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NASA TN D-1796

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LONGITUDINAL STABILITY CHARACTERISTICS  
OF LOW-ASPECT-RATIO WINGS HAVING  
VARIATIONS IN LEADING -  
AND TRAILING-EDGE CONTOURS

*by William P. Henderson*

*Langley Research Center*

*Langley Station, Hampton, Va.*



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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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# LONGITUDINAL STABILITY CHARACTERISTICS OF LOW-ASPECT-RATIO WINGS

## HAVING VARIATIONS IN LEADING- AND TRAILING-EDGE CONTOURS

By William P. Henderson  
Langley Research Center

### SUMMARY

An investigation was made in the Langley high-speed 7- by 10-foot tunnel to determine the longitudinal stability characteristics of a series of related low-aspect-ratio wings having variations in the leading- and trailing-edge contours. The wings of this investigation employed flat-plate airfoil sections. Studies were conducted primarily at a Mach number of 0.40; one of the wings was investigated at Mach numbers of 0.40 and 0.60. The angle of attack was varied from  $-5^{\circ}$  to  $22^{\circ}$ . The test Reynolds number per foot varied from  $2.52 \times 10^6$  at a Mach number of 0.40 to  $3.40 \times 10^6$  at a Mach number of 0.60.

The results of this investigation indicate that removing area from the trailing edge of the basic clipped delta wing results in decreases in the longitudinal stability at low lift coefficients, whereas removing area from the leading edge generally results in increases in the longitudinal stability at moderate lift coefficients. By applying the proper modification to both the leading and trailing edges of the basic clipped delta wing, the aspect ratio can be materially increased with only small losses in the longitudinal stability at moderate lift coefficients. More nearly linear variations of pitching-moment coefficient with lift coefficient can be obtained on the wings with modified leading and trailing edges by the use of a wing leading-edge chord extension.

### INTRODUCTION

The National Aeronautics and Space Administration has been studying various wing planforms in order to obtain a supersonic transport configuration that exhibits acceptable stability and performance characteristics throughout its flight regime. (For example, see refs. 1 and 2.) In reference 3 a series of highly swept low-aspect-ratio wings having variations in the leading-edge contour were investigated at low subsonic speeds and exhibited good stability characteristics but quite low performance potential with respect to low-speed flight. In view of these results an investigation has been conducted on a  $75^{\circ}$  sweptback low-aspect-ratio clipped-delta-wing-body combination on which the wing planform was principally modified by removing area from the wing leading and trailing edges. The modifications were made to determine the extent to which the aspect ratio of the basic wing could be increased without affecting the desirable

stability characteristics. Increasing the aspect ratio would result in a wing with increased performance potential if a favorable load distribution could be maintained.

The purpose of this paper is to present the effect on the static longitudinal stability characteristics of several types of modifications to the wing geometry of the 75° clipped-delta-wing—body combination. This investigation was made in the Langley high-speed 7- by 10-foot tunnel primarily at a Mach number of 0.40; one of the wings was investigated at Mach numbers of 0.40 and 0.60. The Reynolds number per foot of this investigation ranged from  $2.52 \times 10^6$  at a Mach number of 0.40 to  $3.40 \times 10^6$  at a Mach number of 0.60.

## SYMBOLS

The forces and moments measured during this investigation are presented in standard form with the results referred to the wind-axis system. The coefficients for each wing are nondimensionalized with respect to the planform characteristics of that particular wing.

Additionally, the pitching-moment coefficients for each wing planform are presented about, first, the quarter-chord point of the mean geometric chord, and, second, a position which will give each wing a common initial stability level near zero lift. The reference dimensions and the distances to these two moment centers from the nose of the fuselage are given in table I for each wing planform.

A	aspect ratio
b	wing span, in.
$C_D$	drag coefficient, $\frac{\text{Drag}}{qS}$
$C_L$	lift coefficient, $\frac{\text{Lift}}{qS}$
$C_m$	pitching-moment coefficient about moment center that results in common stability level at $C_L \approx 0$ , $\frac{\text{Pitching moment}}{qS\bar{c}}$
$C_{m,\bar{c}/4}$	pitching-moment coefficient about wing quarter-chord point of mean geometric chord, $\frac{\text{Pitching moment}}{qS\bar{c}}$
$\bar{c}$	mean geometric chord, in.
l	fuselage length, in.
q	free-stream dynamic pressure, lb/sq ft

M	Mach number
S	reference area, sq ft
x	distance from fuselage nose (positive rearward of nose), in.
$x_c/4$	distance from quarter-chord point of mean aerodynamic chord (positive forward of moment center), in.
y	distance from fuselage center line to leading edge of wing, in.
$\alpha$	angle of attack, deg
$\Lambda_c/4$	effective sweepback angle of quarter-chord line, deg

### MODELS

The models of this investigation utilized flat-plate wings mounted beneath a fuselage with a vertical tail. Drawings of the configurations tested are shown in figures 1 to 5. The basic wing of this investigation (shown in fig. 1 and designated wing 1) has a clipped delta planform with a leading-edge sweepback angle of  $75^\circ$ , and an aspect ratio of 0.95. Three types of modifications were made to the trailing edge of this basic wing planform and resulted in the planforms of wings 2 to 11 as shown in figures 2 and 3. Two types of leading-edge modifications were used in the planforms of wings 12 to 14, and 18 to 20, as shown in figures 3 and 5. In addition, several combinations of these leading- and trailing-edge modifications were incorporated in wings 15 to 17, and 21 to 23, as shown in figures 4 and 5.

All the wings of this investigation were 3/16-inch-thick flat plates with rounded leading edges and blunt trailing edges. Outboard leading-edge chord extensions shown in figure 1 were investigated in combination with several of the wing planform variations of this study. No attempt was made to fair the wings into the fuselage. (See fig. 1.)

### TESTS AND CORRECTIONS

The investigation was made in the Langley high-speed 7- by 10-foot tunnel primarily at a Mach number of 0.40, which corresponds to a dynamic pressure of 212 pounds per square foot and a Reynolds number per foot of  $2.52 \times 10^6$ . An additional wind-tunnel test was made on wing 16 at a Mach number of 0.60, which corresponds to a dynamic pressure of 419 pounds per square foot and a Reynolds number per foot of  $3.40 \times 10^6$ .

Lift, drag, and pitching moment were measured by use of an internal electrical strain-gage balance through an angle-of-attack range of  $-5^\circ$  to  $22^\circ$ . The angle of attack was corrected for deflection of the sting support system under

load. No attempt has been made to correct the data for any aeroelastic distortion that might be present. The drag data were corrected so that the fuselage base pressure was equal to free-stream static pressure. No artificial transition strips were employed on the wings. Jet-boundary and blockage corrections are negligible for the open-slot configuration of the tunnel, and therefore, were not applied.

## PRESENTATION OF DATA

In order to aid in comparing the pitching moments for the various wing planforms, the pitching-moment coefficients are presented about the quarter-chord point of the mean geometric chord and also about a moment center that results in a common initial stability level (5 percent of the mean geometric chord) at a lift coefficient of approximately zero. The data figures are presented as follows:

	Figure
Effect of wing planform on the longitudinal aerodynamic characteristics, leading-edge chord extension off:	
Wings 1 to 4 . . . . .	6
Wings 1, 2, and 5 to 7 . . . . .	7
Wings 1, 2, and 8 to 11 . . . . .	8
Wings 1, and 12 to 14 . . . . .	9
Wings 13, and 15 to 17 . . . . .	10
Wings 1, and 18 to 20 . . . . .	11
Wings 20 to 23 . . . . .	12
Geometric variables and the type of pitching-moment curve obtained for the various wings investigated . . . . .	13
Effect of leading-edge chord extension on the longitudinal aerodynamic characteristics:	
Wing 15 . . . . .	14
Wing 16 . . . . .	15
Wing 17 . . . . .	16
Combined effect of Mach number and Reynolds number on the longitudinal aerodynamic characteristics of wing 16, leading-edge chord extension off . . . . .	17

## RESULTS AND DISCUSSION

Since the main interest of this investigation was in the stability characteristics exhibited by modifications to a highly swept clipped-delta-wing planform, the wings employed flat-plate airfoil sections in order to minimize fabrication time. No attempt was made to blend the wings with the fuselage employed. The reader is advised, therefore, to view the drag data presented with caution. The drag data are included herein without analysis simply to afford the reader an opportunity to observe the effects of the flat-plate-wing modifications on induced drag.

In order to aid in comparing the pitching-moment-coefficient variations with lift coefficient for the various modifications made to the basic clipped delta wing, only the data transferred to a moment-center location which will result in a common stability level will be discussed herein. The results of figures 6 and 7 indicate that removing area from the trailing edge of the basic wing in the manner shown in figure 2 results in a progressive loss in longitudinal stability at relatively low lift coefficients for wings 2 to 7. As indicated in figure 8, modifying the trailing edge of wing 2 to produce wing 8 results in a sizable increase in the level of the longitudinal stability at lift coefficients above 0.20. These data shown in figure 8 also indicate that removing area from the trailing edge of wing 8 in the manner shown in figure 3 to obtain wings 9 and 10 results in a progressive loss in longitudinal stability at low lift coefficients. However, further removal of area from the trailing edge of wing 10 to obtain wing 11 results in essentially no change in the pitching-moment variation with lift coefficient.

Removal of area from the trailing edge of wing 1 or wing 8 (to obtain wings 2 to 7 or 9 to 11) results in a wing that has shorter local chords along the wing span. It is characteristic of wings that a decrease in the local chords results in an increased tendency for the flow to separate over the wing (decreasing the lift), especially over the outboard portion of sweptback wings. It is believed that the decrease in longitudinal stability exhibited by wings 2 to 7 and 9 to 11 is associated with the loss in lift that occurs over the outboard portion of the wing. Flow visualization studies conducted on a highly swept delta wing, presented in reference 4, have shown this separation of the flow over the outboard portion of the wing.

The effect of modifying the leading edge of the basic wing to obtain wings 12 to 14 and 18 to 20 is shown in figures 9 and 11, respectively. These data (transferred to a common stability level) indicate that notching or cutting away part of the wing leading edge results in an increase in the longitudinal stability at the higher lift coefficients for all the wings of this series except wing 14 which showed a slight decrease in longitudinal stability at the higher lift coefficients. The reason for the decrease in stability exhibited by wing 14 is not fully understood; however, it is believed to be associated with the vortex which originates inboard of the wing apex. Further study is necessary in order to provide sufficient information to fully analyze the effects of this vortex.

Wings incorporating modifications to both the leading and trailing edges (wings 15 to 17 and 21 to 23) were investigated, and the results are presented in figures 10 and 12. These data indicate that linear variations of pitching-moment coefficient with lift coefficient, as exhibited by wing 1, were not obtained for these composite planforms. However, these composite planforms show improvements over those planforms which have only the wing trailing edge modified.

Figure 13 provides some generalization as to the effect of the geometric variables on the linearity of the pitching-moment curves of the wings of the present investigation. This figure shows a comparison of the aspect ratio and the sweep angle of the quarter-chord line for these wings. Also shown in this figure, by use of the symbols appearing within each wing planform, is the type

of pitching-moment-coefficient variation with lift coefficient obtained for each wing planform. The criterion used in establishing these symbols considers the deviation of the pitching-moment curve at any positive lift coefficient below maximum lift from its slope at zero lift. If the slope of the pitching-moment curve is either linear or increases at the higher lift coefficients, an open symbol is used for that wing; whereas, a half-open half-solid symbol indicates a loss in stability of less than 5-percent  $\bar{c}$ , and a solid symbol a loss greater than 5-percent  $\bar{c}$ .

The data of figure 13 indicate that only a few wings of this investigation (wings 5, 12, and 13), on which the aspect ratio was increased, maintained the desirable stability characteristics exhibited by the basic wing (wing 1). The data of this figure, however, along with the data of figure 10 indicate that by modifying both the leading and trailing edges the aspect ratio of the basic wing can be materially increased (wings 15 and 16) with only small losses in the longitudinal stability at moderate lift coefficients.

Placing the outboard leading-edge chord extensions shown in figure 1 on wings 15, 16, and 17 results in a more linear variation of pitching-moment coefficient with lift coefficient. (See figs. 14, 15, and 16.) The effects of these chord extensions are similar to those previously shown for their use on a  $45^\circ$  sweptback wing reported on in reference 5.

The combined effect of Mach number and Reynolds number on the longitudinal stability characteristics of the configuration with wing 16 is presented in figure 17. These data indicate that increasing the Mach number from 0.40 to 0.60 and the Reynolds number from  $2.52 \times 10^6$  to  $3.40 \times 10^6$  results in a more nearly linear variation of pitching-moment coefficient with lift coefficient.

## CONCLUSIONS

Results of an investigation to determine the longitudinal stability characteristics of a series of related low-aspect-ratio wings having variations in the leading- and trailing-edge contours indicate the following conclusions:

1. Removing area from the trailing edge of the basic clipped delta wing results in decreases in the longitudinal stability at low lift coefficients, whereas removing area from the leading edge generally results in increases in the longitudinal stability at moderate lift coefficients.
2. By modifying both the leading and trailing edges of the basic clipped delta wing the aspect ratio can be materially increased with only small losses in the longitudinal stability at moderate lift coefficients.

3. More nearly linear variations of pitching-moment coefficient with lift coefficient can be obtained on the wings with modified leading and trailing edges by the use of a wing leading-edge chord extension.

Langley Research Center,  
National Aeronautics and Space Administration,  
Langley Station, Hampton, Va., July 20, 1964.

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TABLE I.- REFERENCE DIMENSIONS, DISTANCES TO THE MOMENT CENTERS, AND  
LOCATION OF THE WING AERODYNAMIC CENTER FOR EACH WING PLANFORM

Wing	Reference area, sq ft	Reference $\bar{c}$ , in.	Aspect ratio	Quarter-chord location, $x/l$	Moment center of transferred data, $x/l$	Aerodynamic- center location, $x_c/4/\bar{c}$
1	1.8681	20.7361	0.95	0.4971	0.5596	-0.178
2	1.3076	14.9602	1.35	.4701	.5211	-.195
3	1.1056	12.0352	1.60	.4630	.5083	-.210
4	1.0306	10.2480	1.72	.4447	.4896	-.236
5	1.6215	19.3062	1.09	.4820	.5392	-.176
6	1.5022	17.8162	1.18	.4755	.5317	-.184
7	1.4211	15.8249	1.24	.4654	.5268	-.215
8	2.0056	23.8296	.88	.4995	.5438	-.129
9	1.6910	20.7556	1.05	.4764	.5374	-.175
10	1.5528	18.9893	1.14	.4701	.5353	-.196
11	1.5000	17.2963	1.18	.4634	.5281	-.209
12	1.7117	18.3707	1.03	.5385	.5623	-.105
13	1.5561	16.2156	1.14	.5781	.5819	-.060
14	1.4044	14.3196	1.26	.6089	.6082	-.048
15	1.3833	15.0482	1.28	.5680	.5648	-.041
16	1.2844	13.5337	1.38	.5621	.5564	-.032
17	1.1928	12.4499	1.48	.5628	.5566	-.029
18	1.7356	18.5179	1.02	.5343	.5635	-.117
19	1.6672	17.3209	1.06	.5482	.5698	-.103
20	1.5917	16.4398	1.11	.5674	.5782	-.078
21	1.2511	12.5844	1.41	.5487	.5591	-.085
22	1.0722	10.7617	1.65	.5432	.5473	-.066
23	.9056	8.9295	1.95	.5385	.5398	-.056

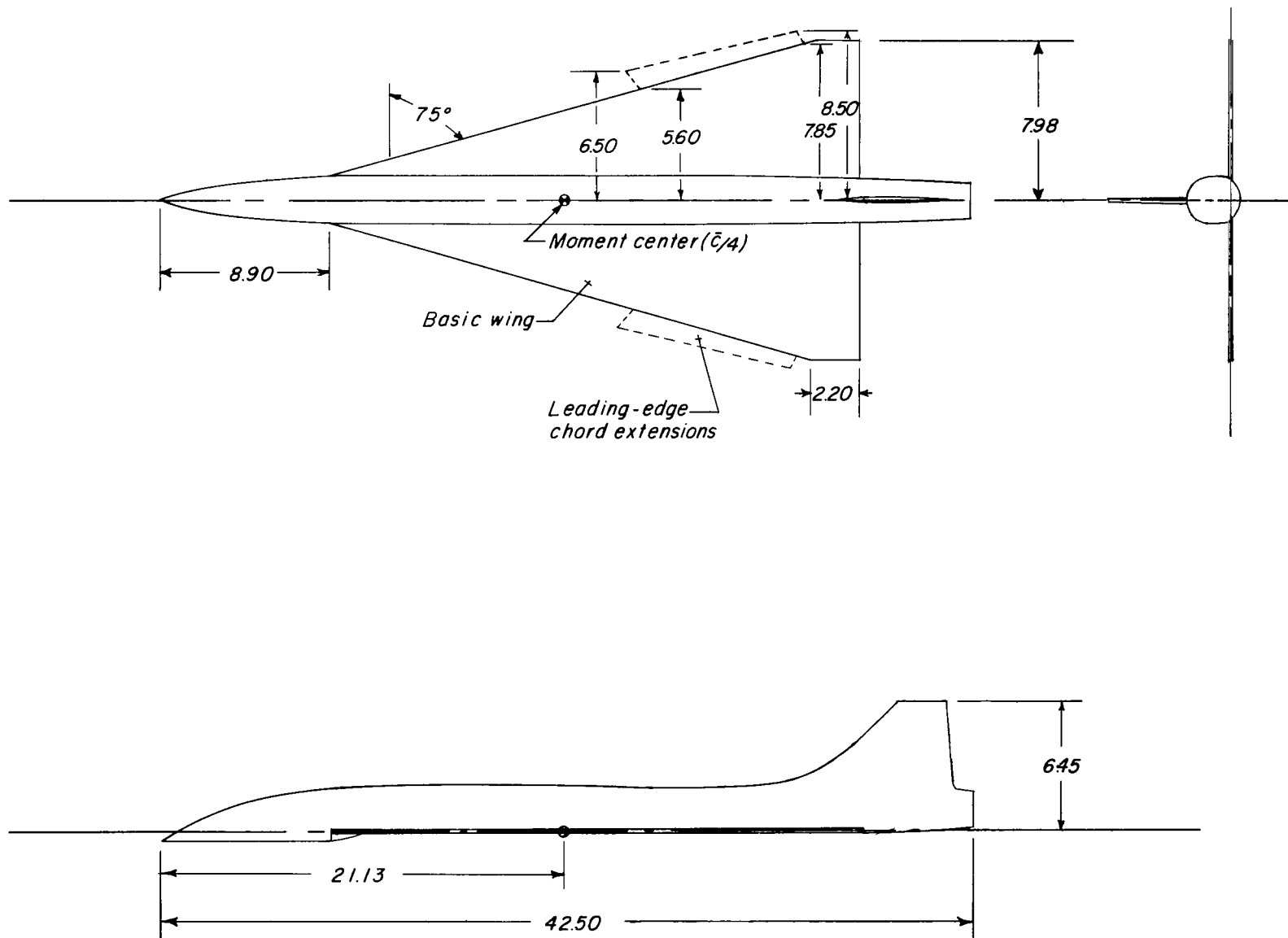


Figure 1.- Geometric dimensions of basic wing-body configuration and leading-edge chord extension.  
All dimensions are in inches.

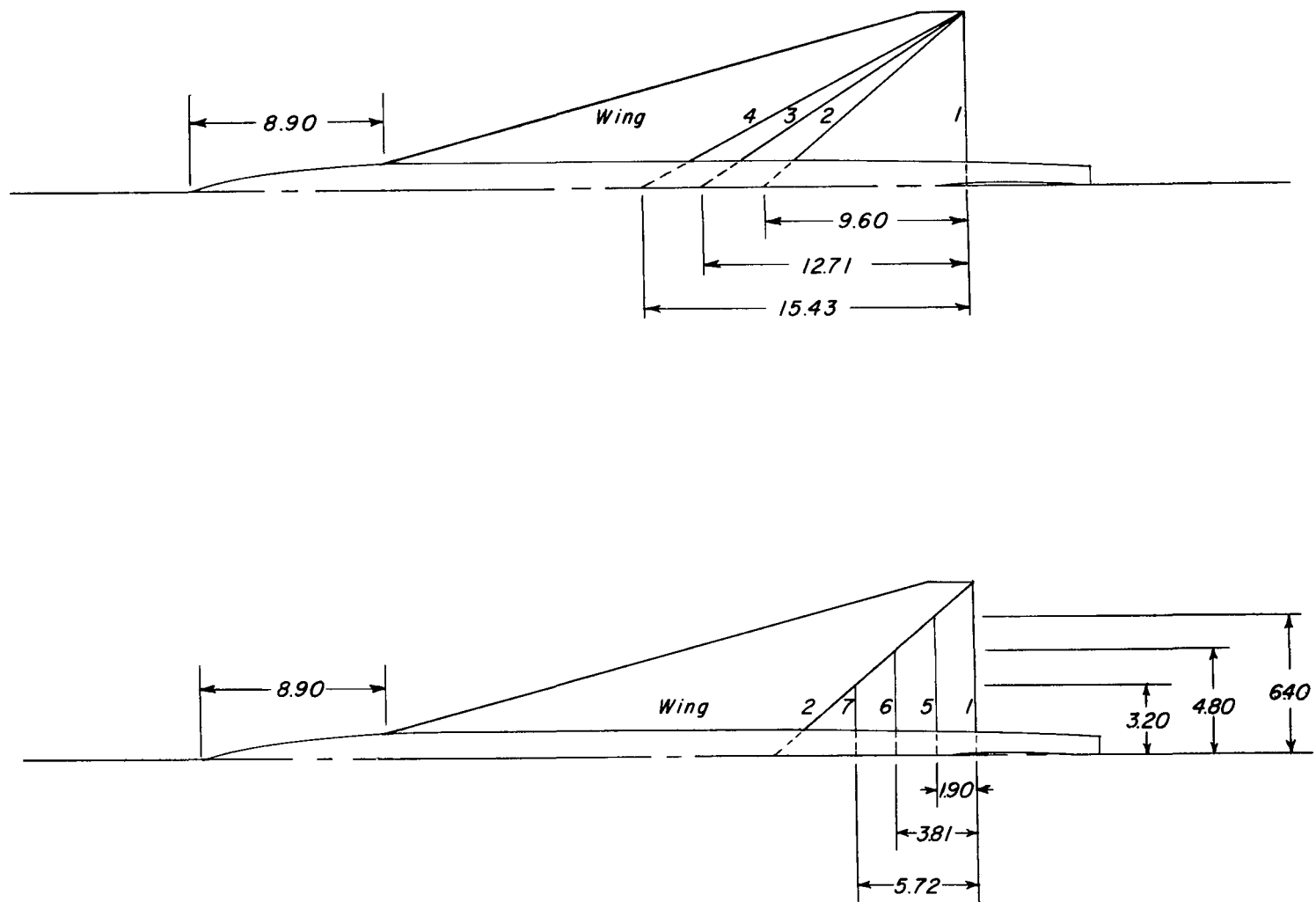


Figure 2.- Geometric dimensions of wings 1 to 7. All dimensions are in inches.

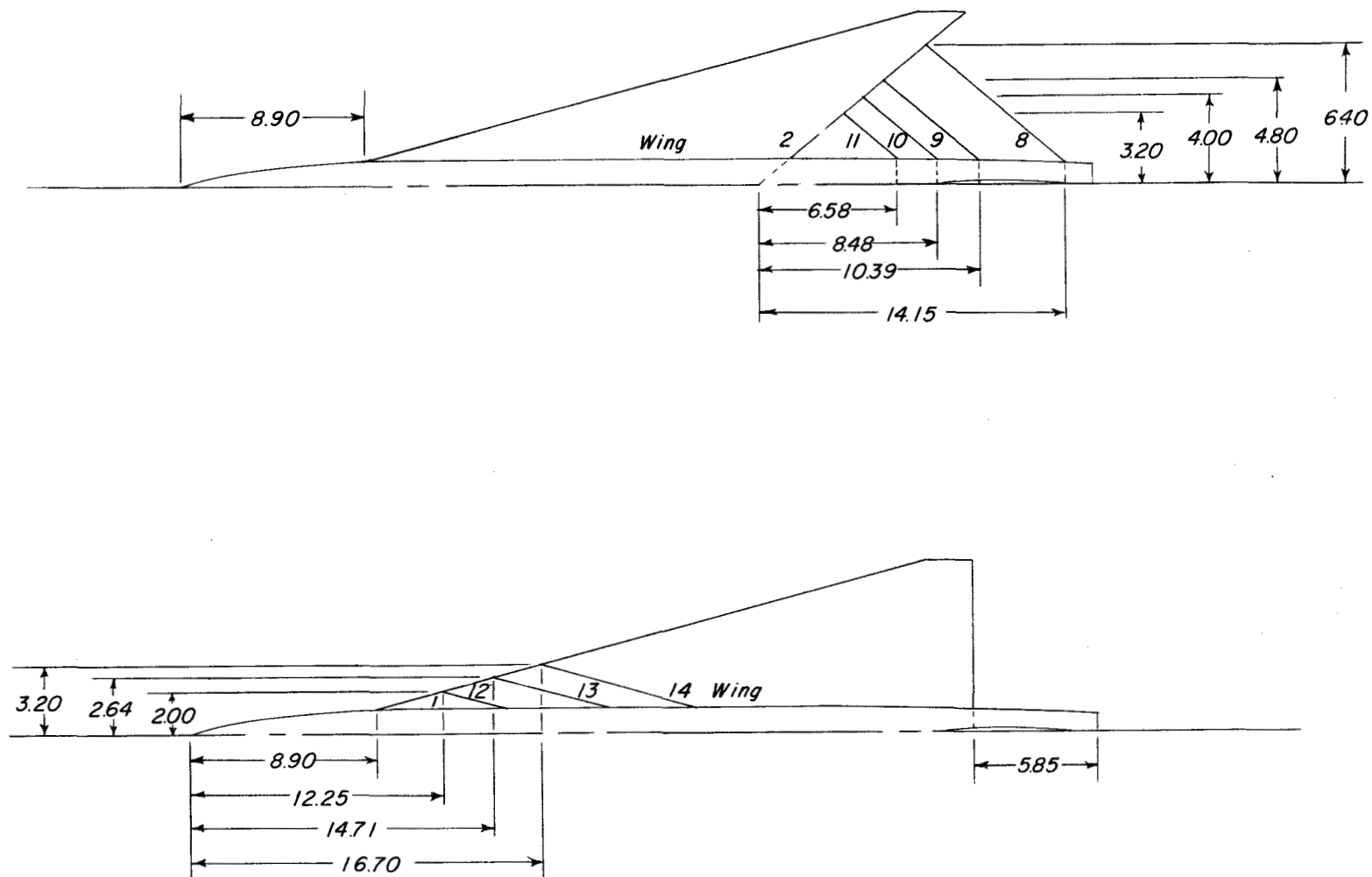


Figure 3.- Geometric dimensions of wings 8 to 14. All dimensions are in inches.

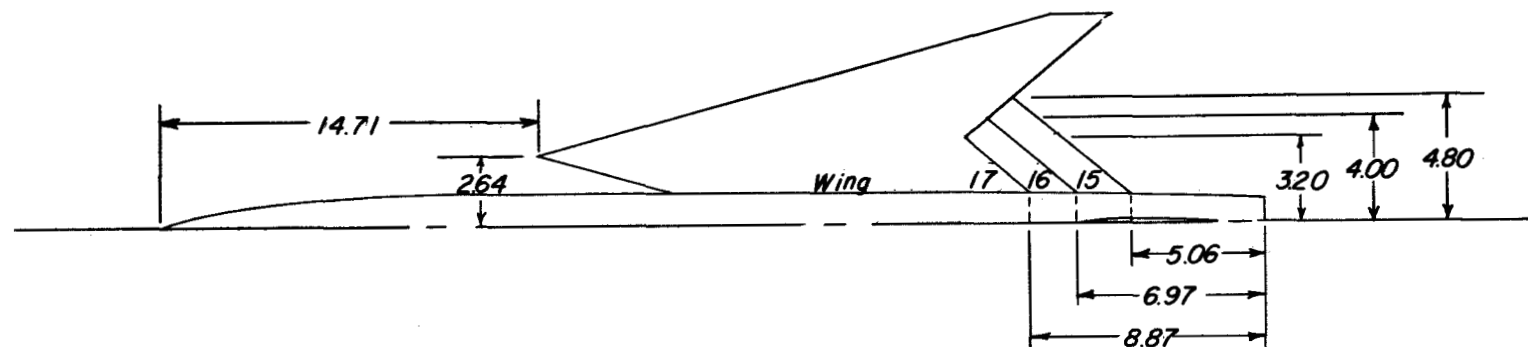
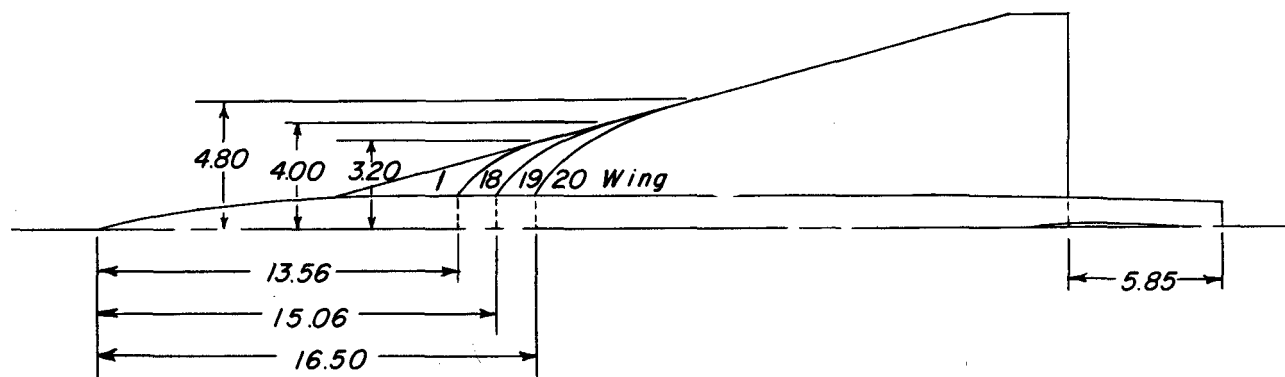


Figure 4.- Geometric dimensions of wings 15 to 17. All dimensions are in inches.



Ordinates for leading edge of wing:					
18		19		20	
$x/l$	$y/b/2$	$x/l$	$y/b/2$	$x/l$	$y/b/2$
0.32	0.14	0.36	0.14	0.39	0.14
.33	.21	.38	.27	.40	.24
.35	.30	.40	.36	.42	.36
.38	.37	.42	.43	.45	.44
.39	.40	.45	.48	.47	.50
		.46	.50	.49	.54
				.53	.60

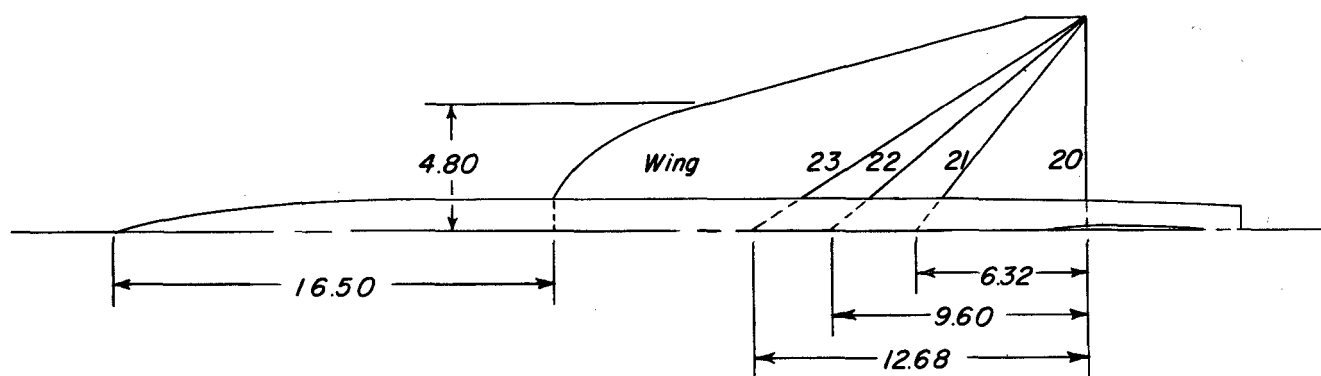


Figure 5.- Geometric dimensions of wings 18 to 23. All dimensions are in inches.

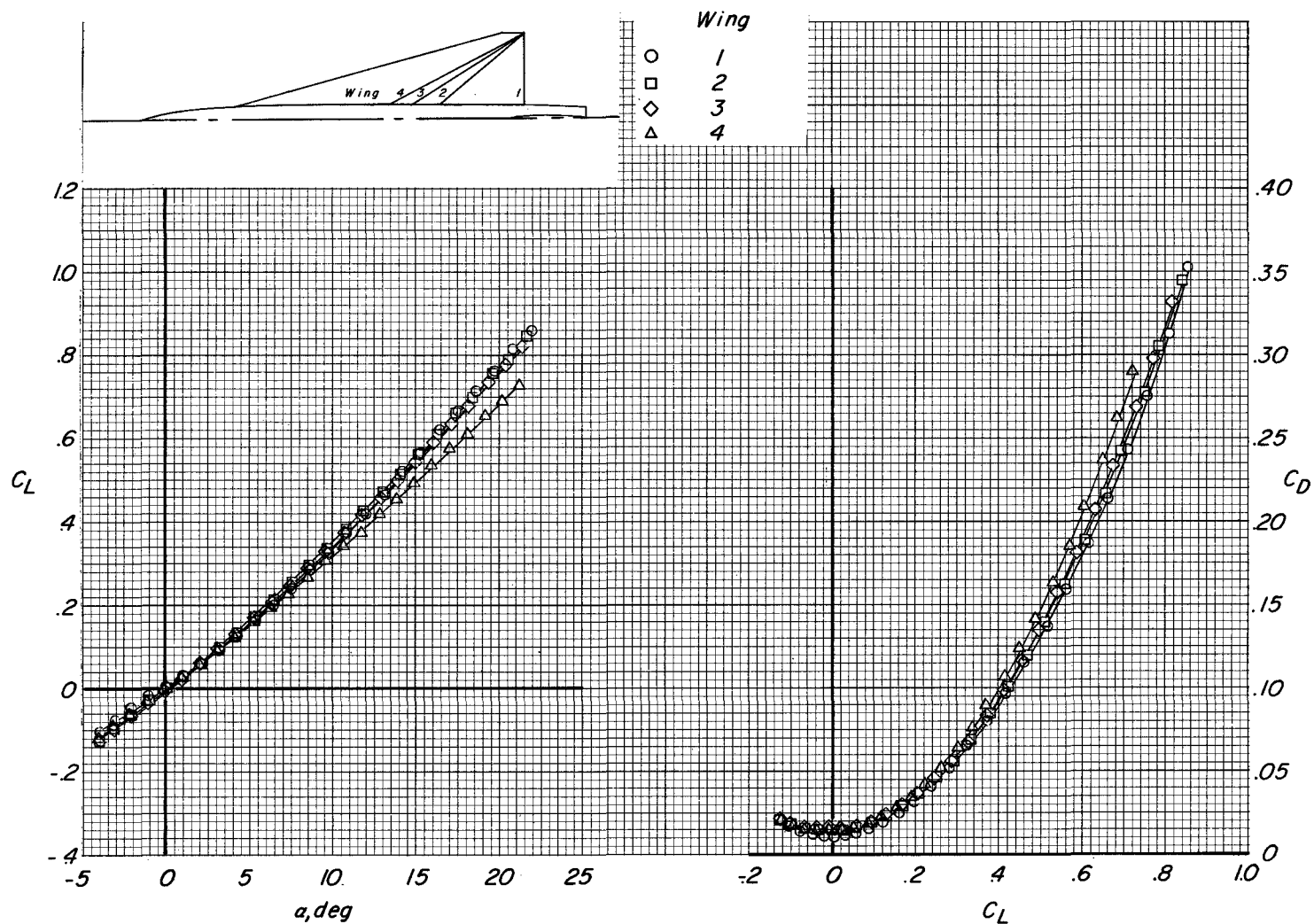


Figure 6.- Effect of wing planform on the longitudinal aerodynamic characteristics. Wings 1 to 4;  
 $M = 0.40$ ; leading-edge chord extension off.

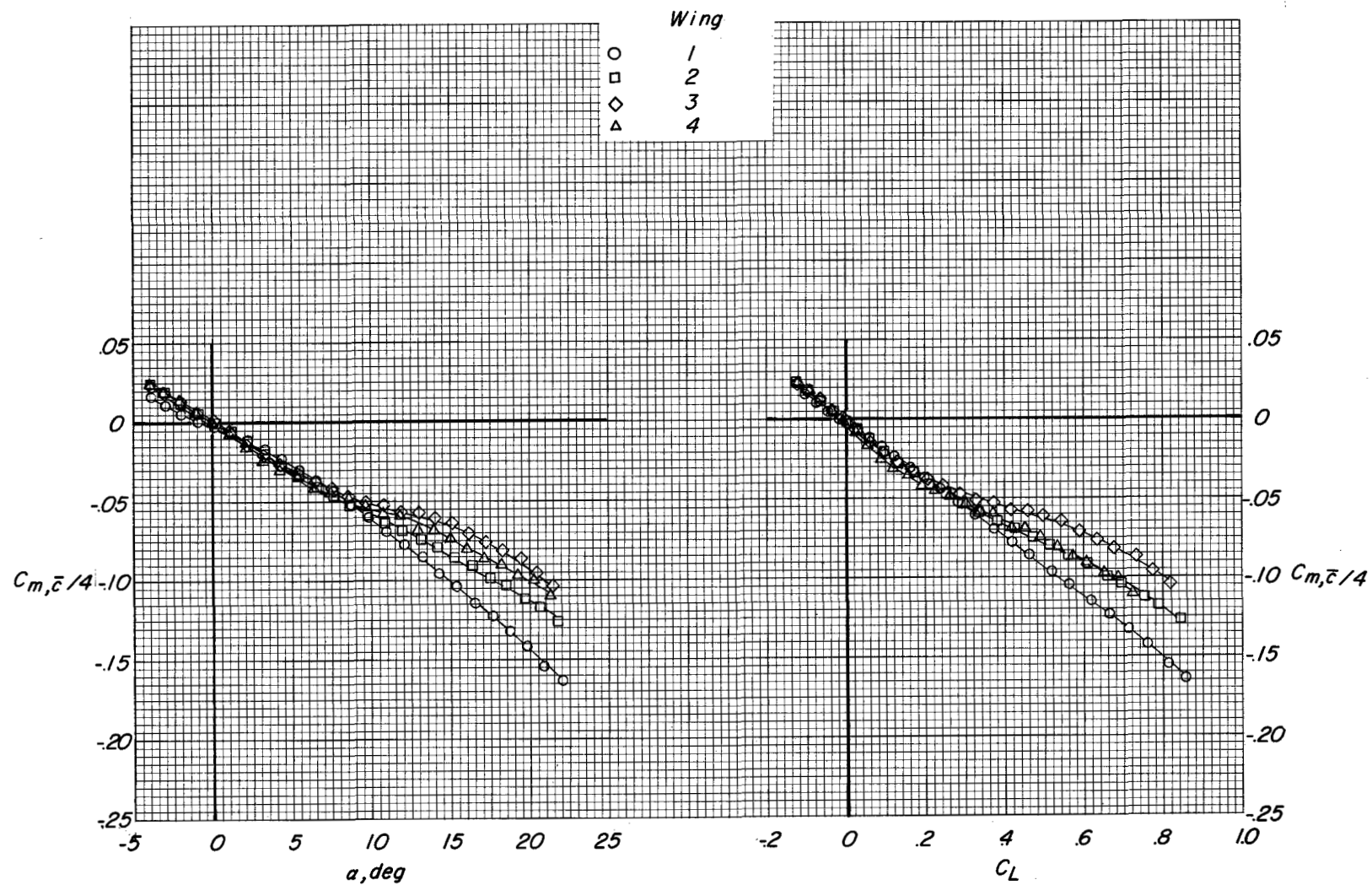


Figure 6.- Continued.

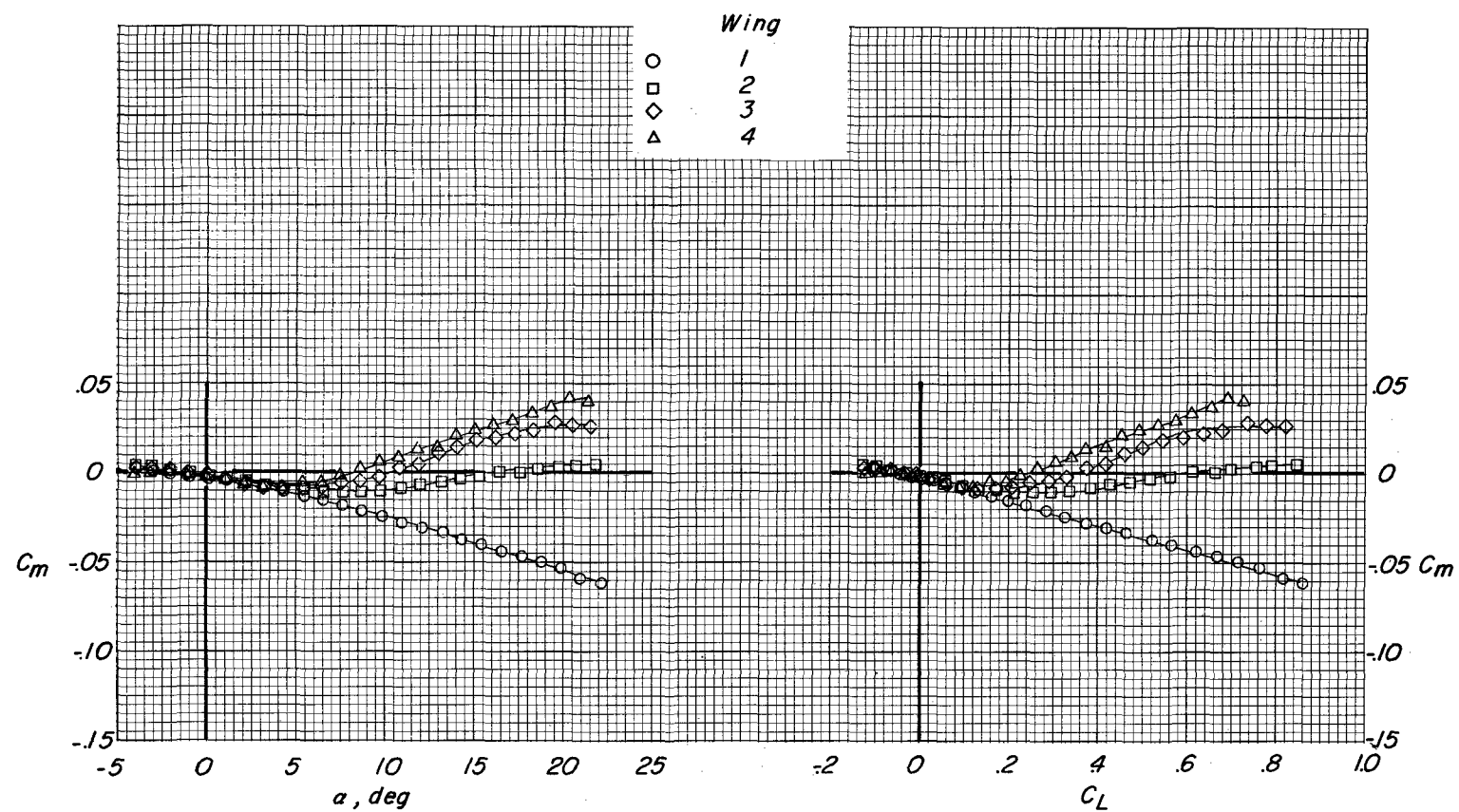


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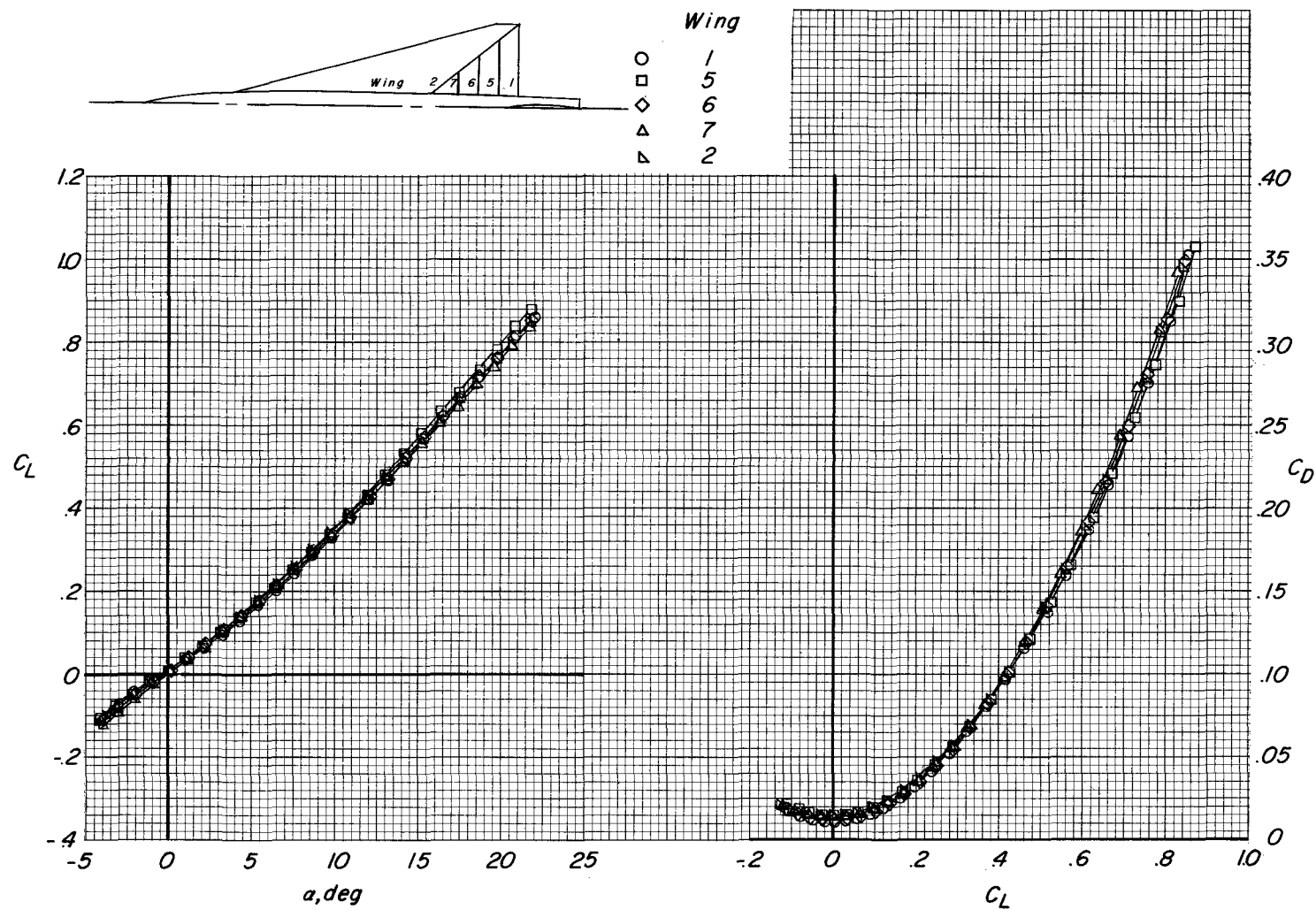


Figure 7.- Effect of wing planform on the longitudinal aerodynamic characteristics. Wings 1, 2, and 5 to 7;  
 $M = 0.40$ ; leading-edge chord extension off.

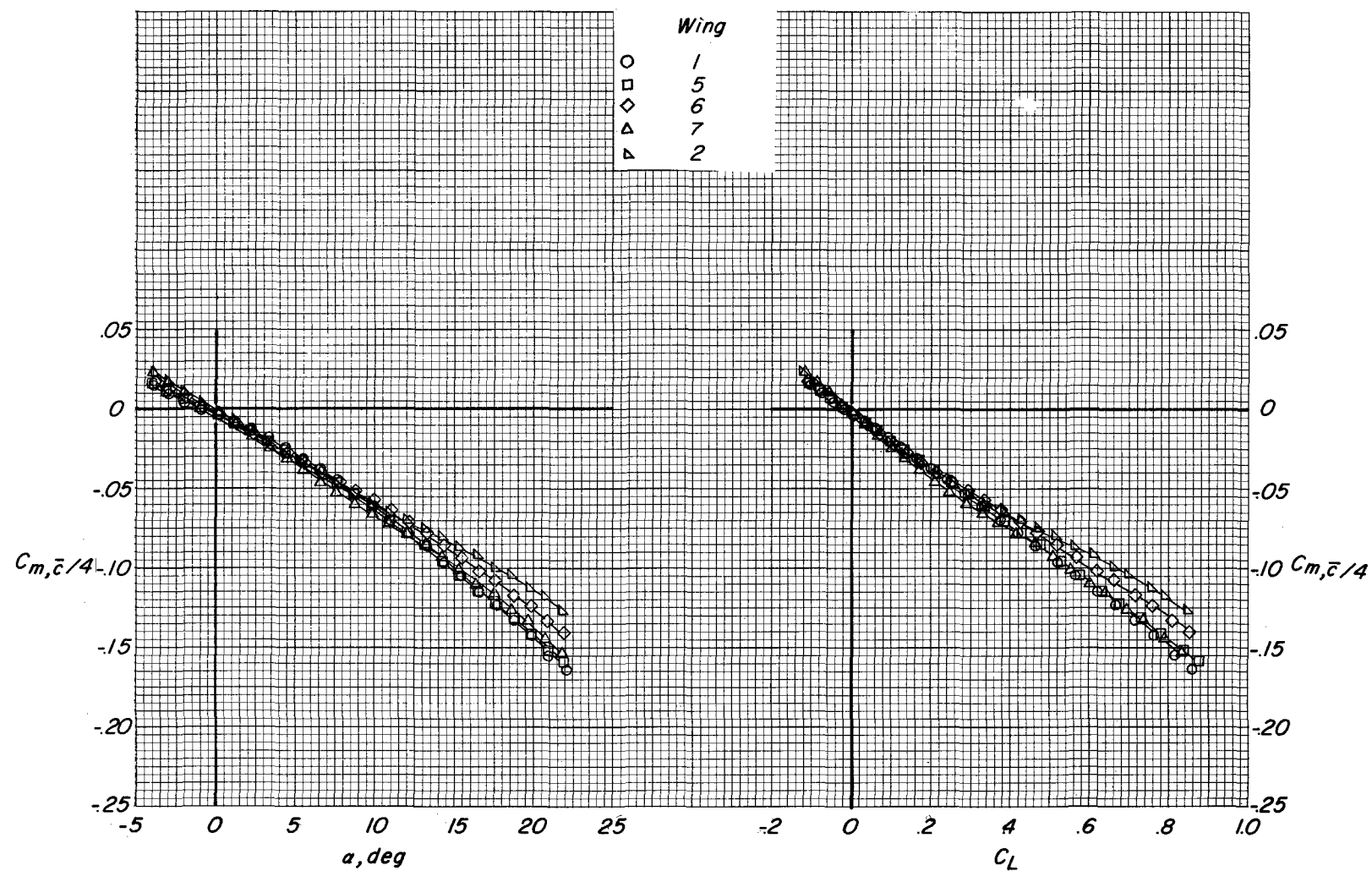


Figure 7.- Continued.

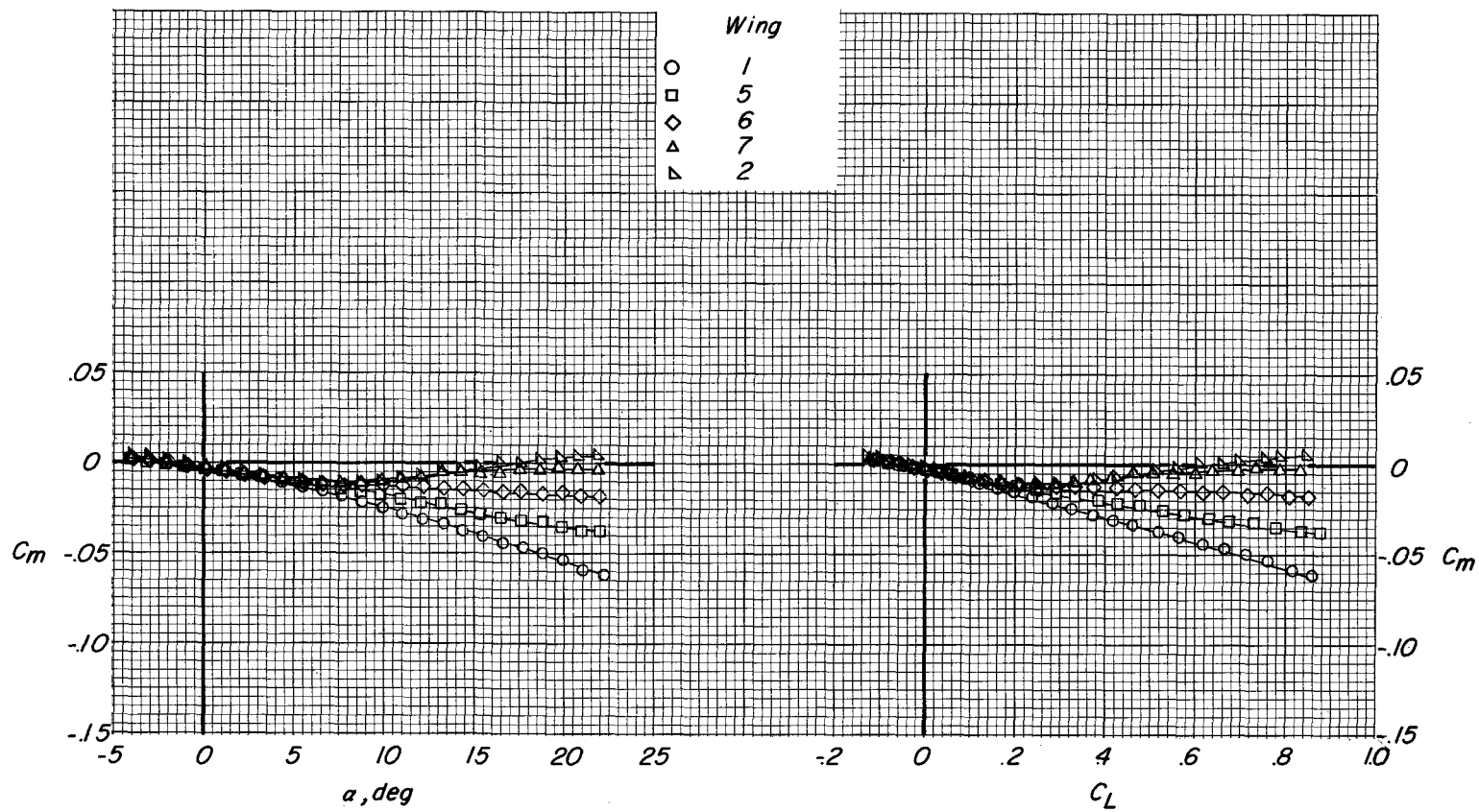


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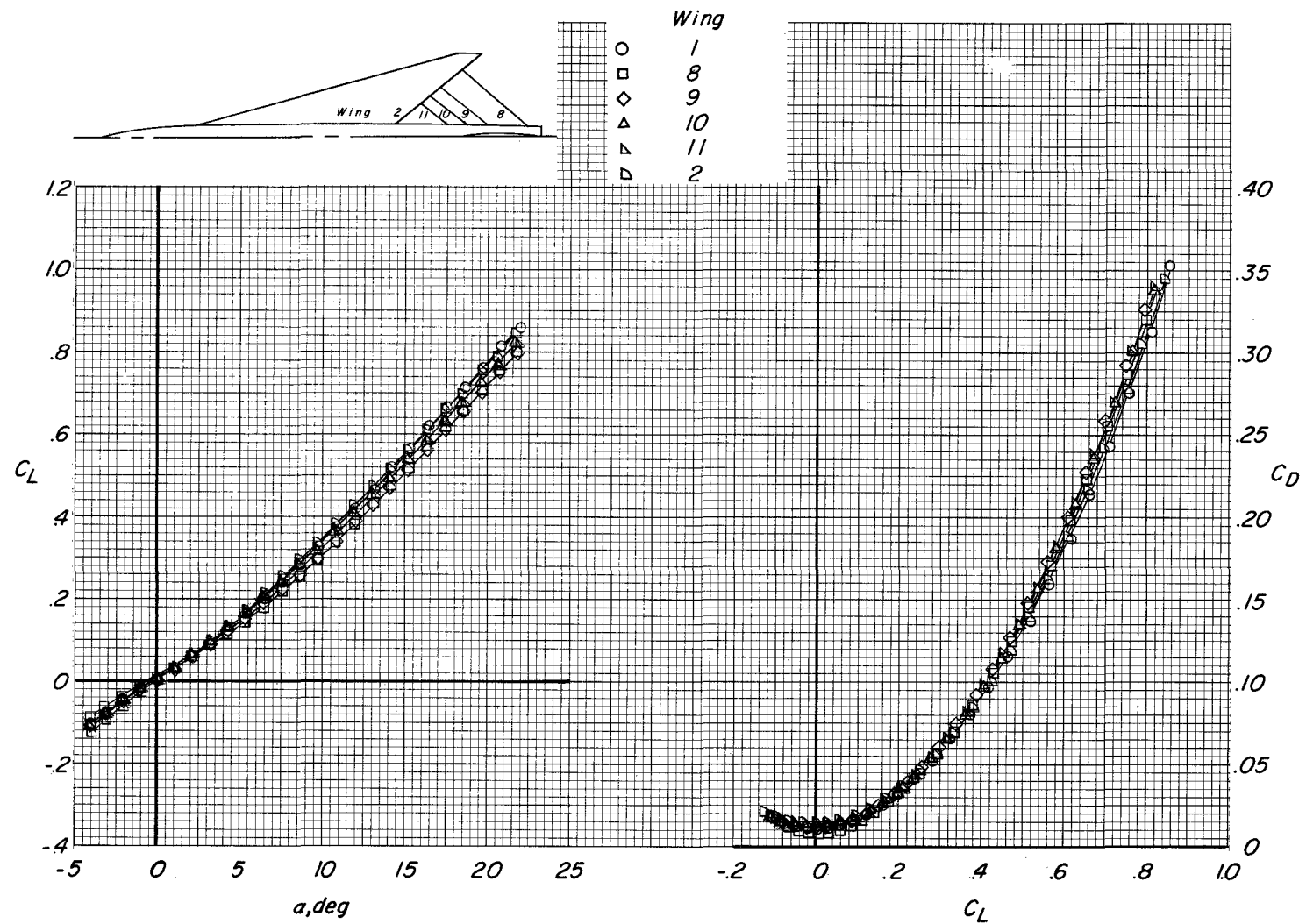


Figure 8.- Effect of wing planform on the longitudinal aerodynamic characteristics. Wings 1, 2, and 8 to 11;  $M = 0.40$ ; leading-edge chord extension off.

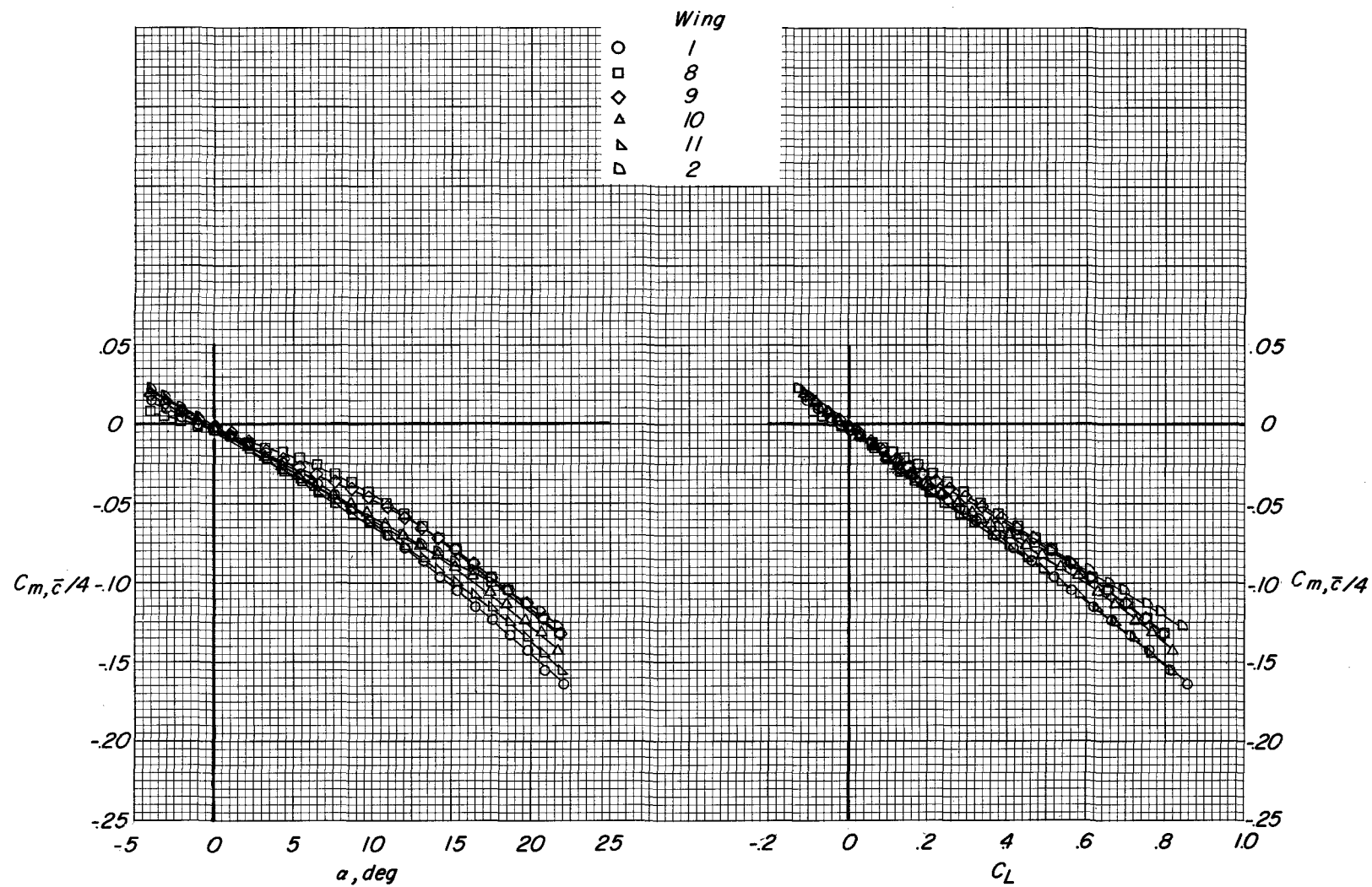


Figure 8.- Continued.

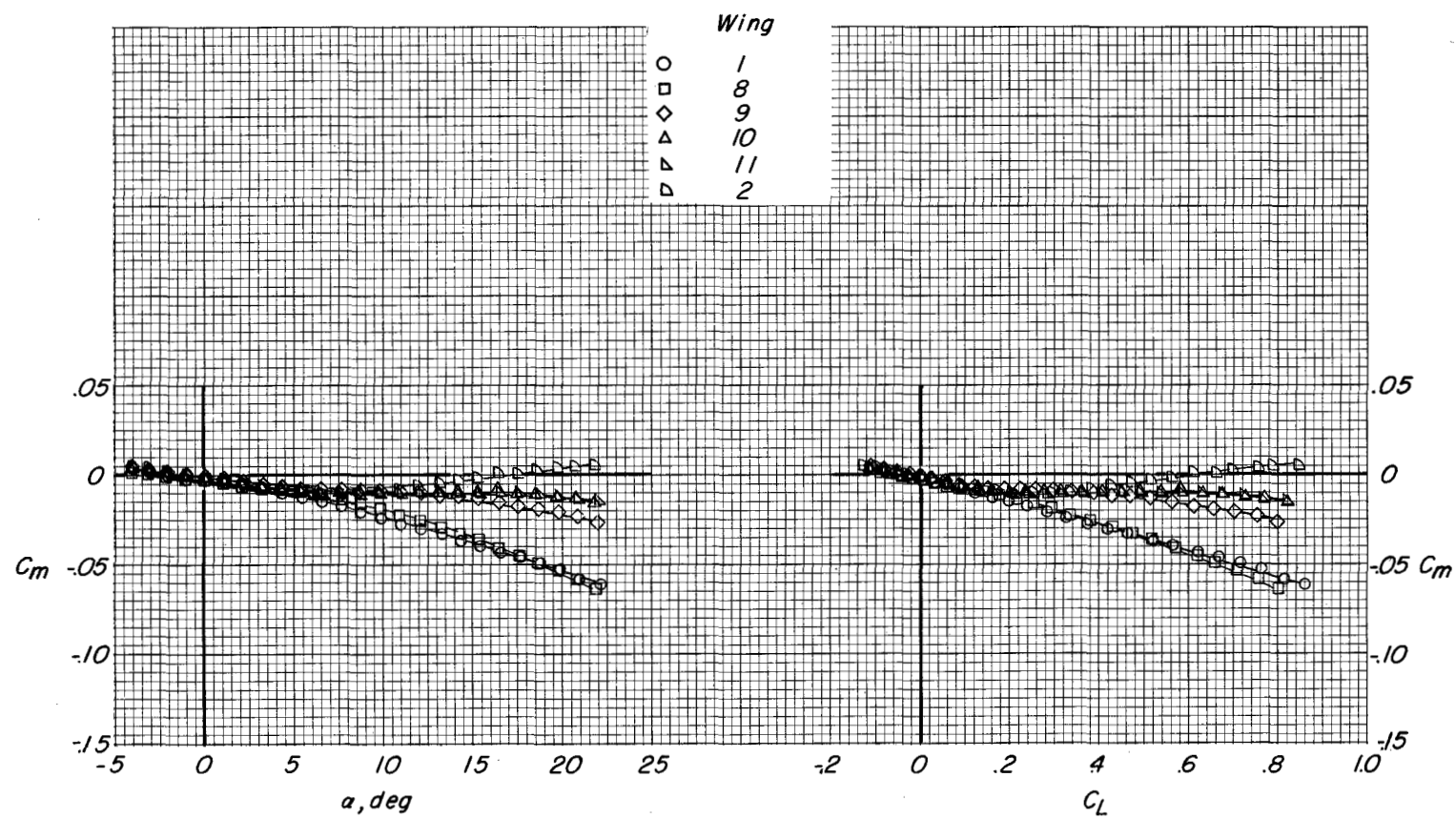


Figure 8.- Concluded.

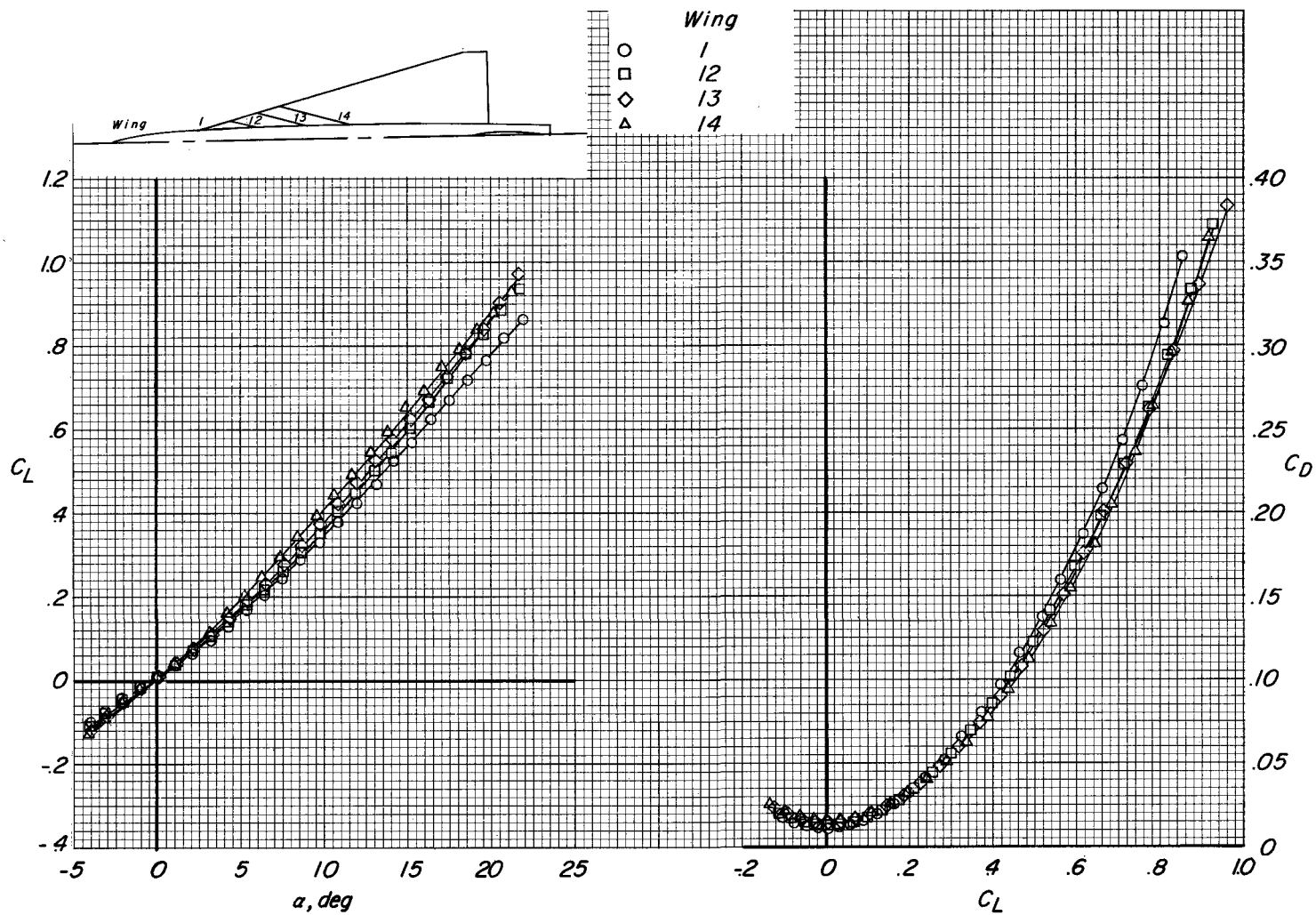


Figure 9.- Effect of wing planform on the longitudinal aerodynamic characteristics. Wings 1 and 12 to 14;  
 $M = 0.40$ ; leading-edge chord extension off.

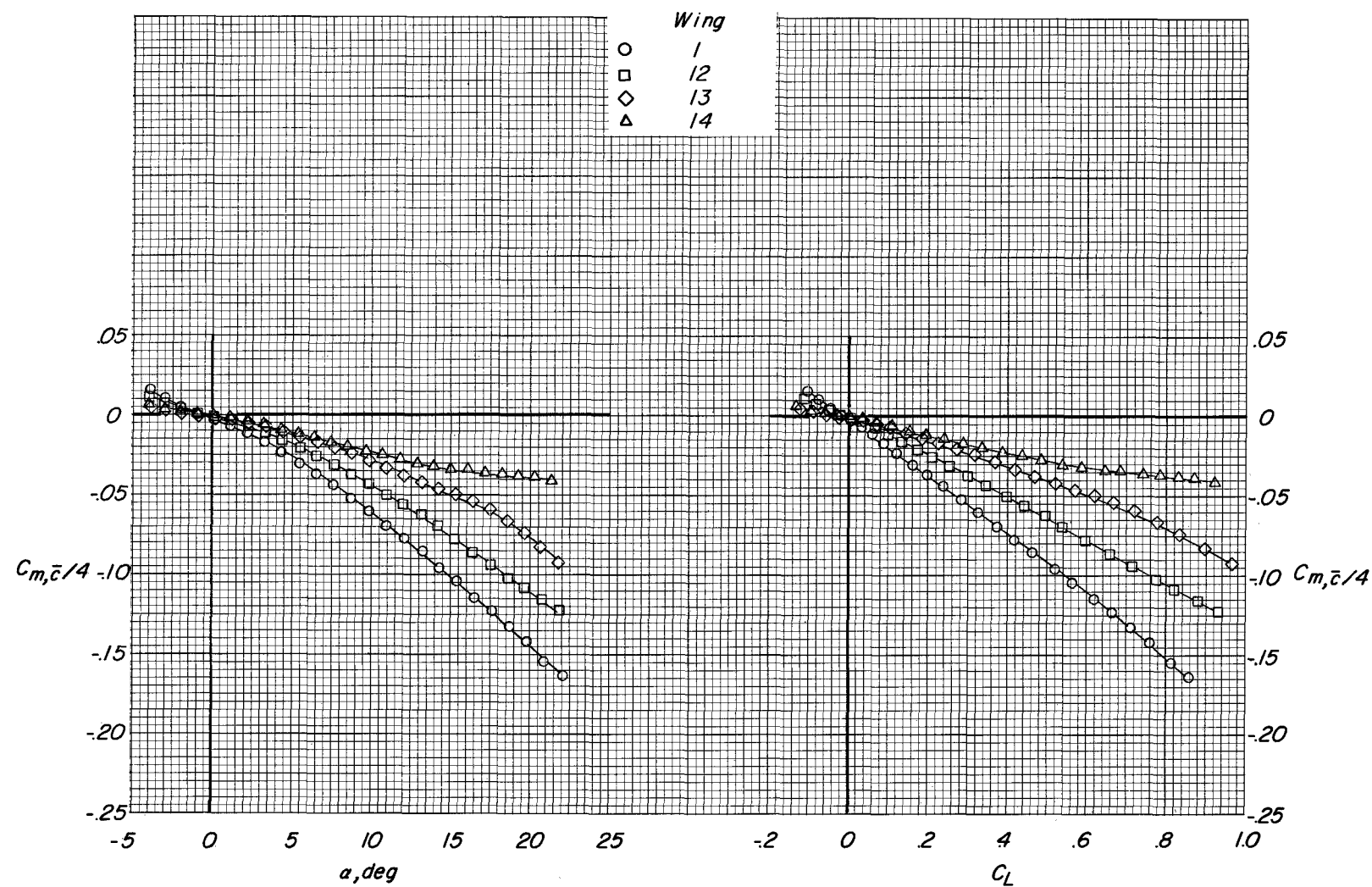


Figure 9.- Continued.

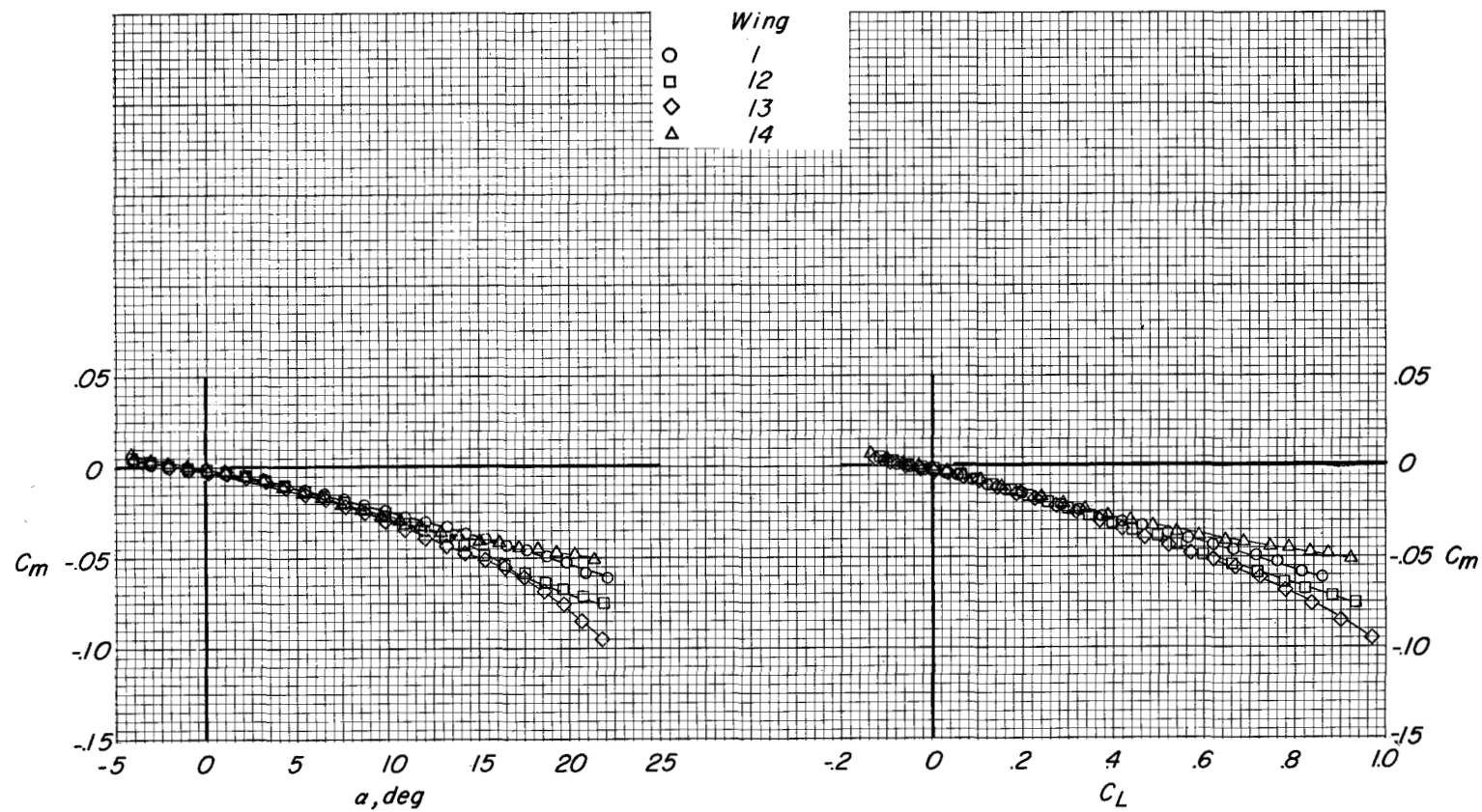


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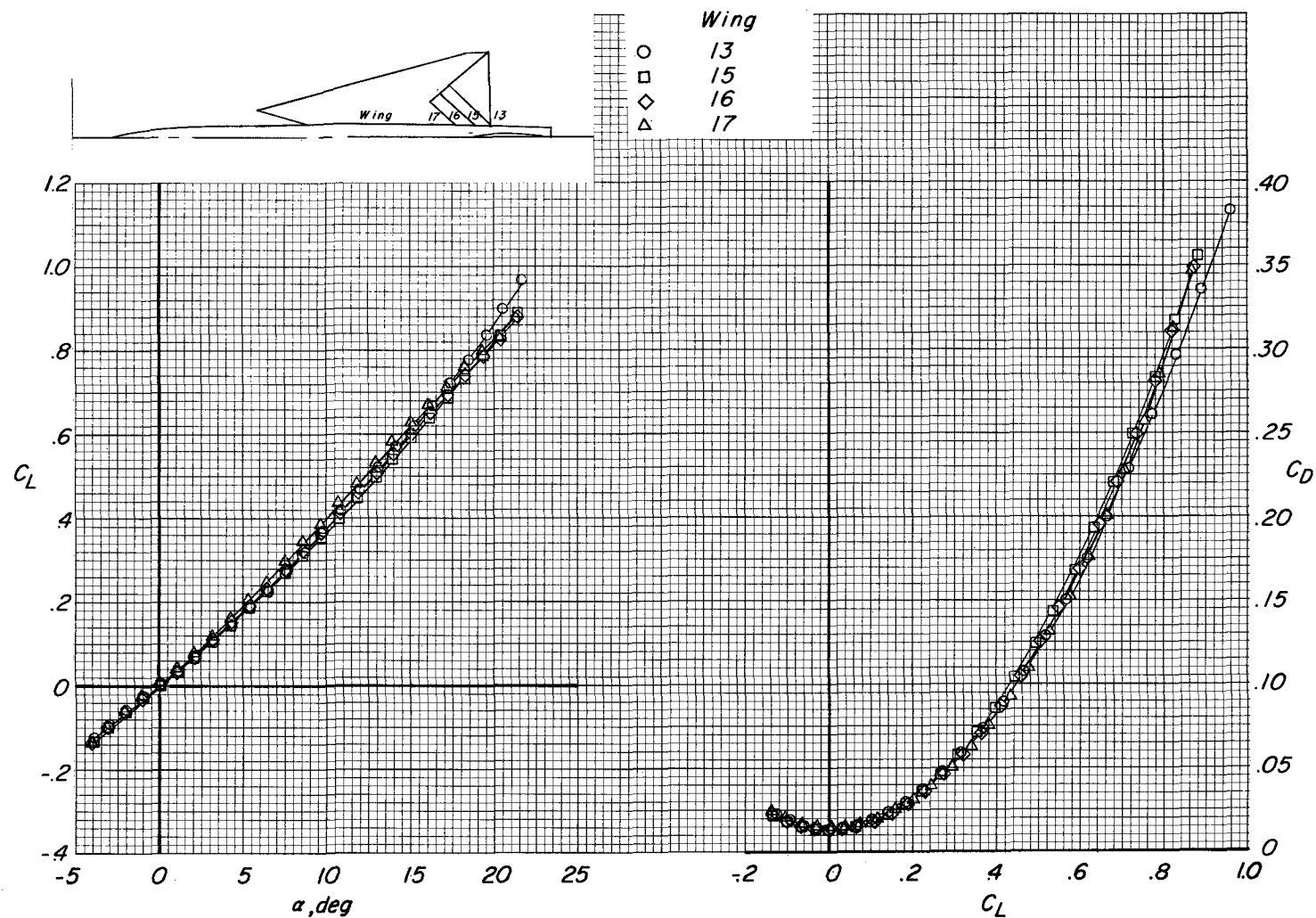


Figure 10.- Effect of wing planform on the longitudinal aerodynamic characteristics. Wings 13 and 15 to 17;  
 $M = 0.40$ ; leading-edge chord extension off.

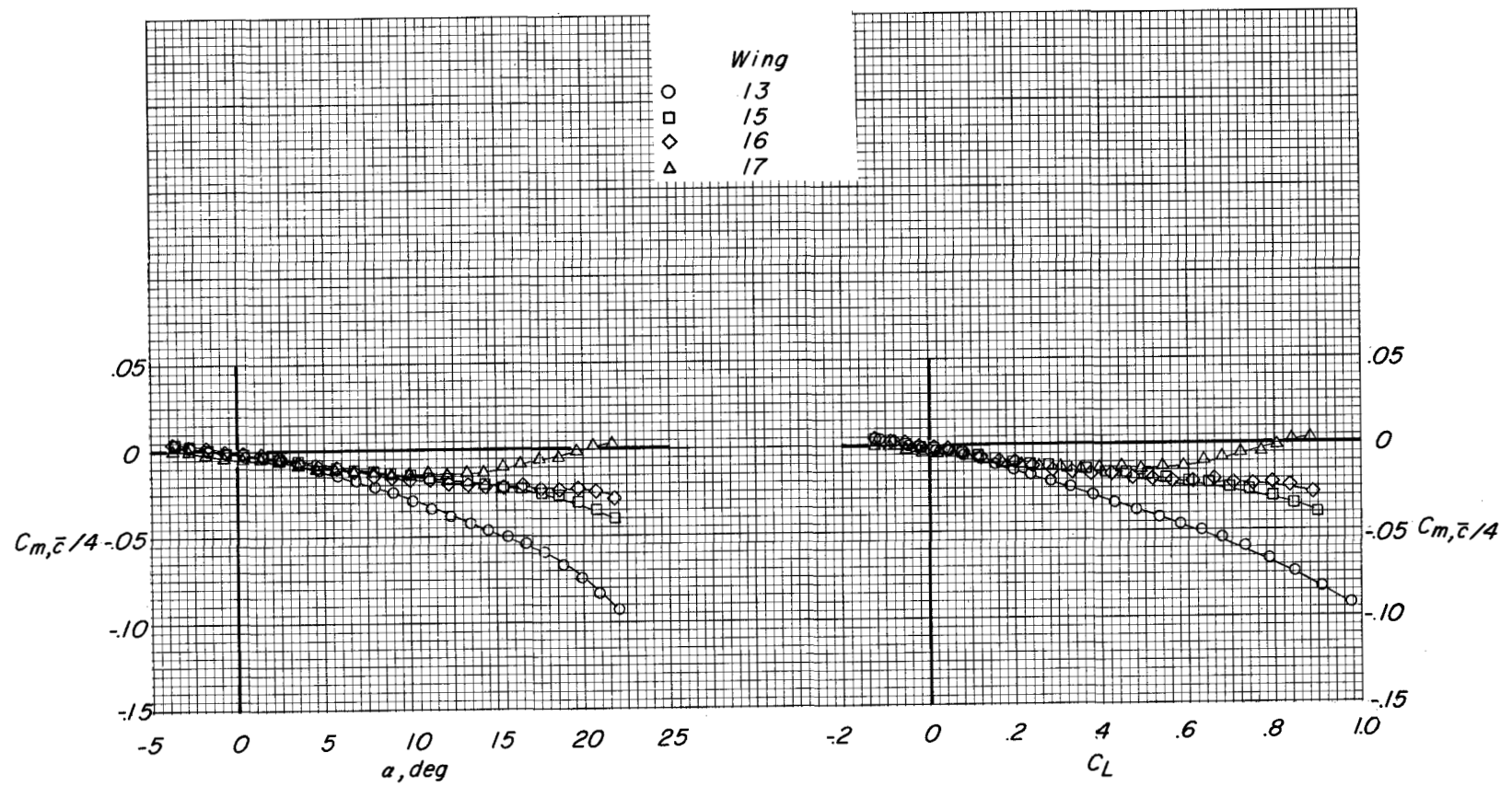


Figure 10.- Continued.

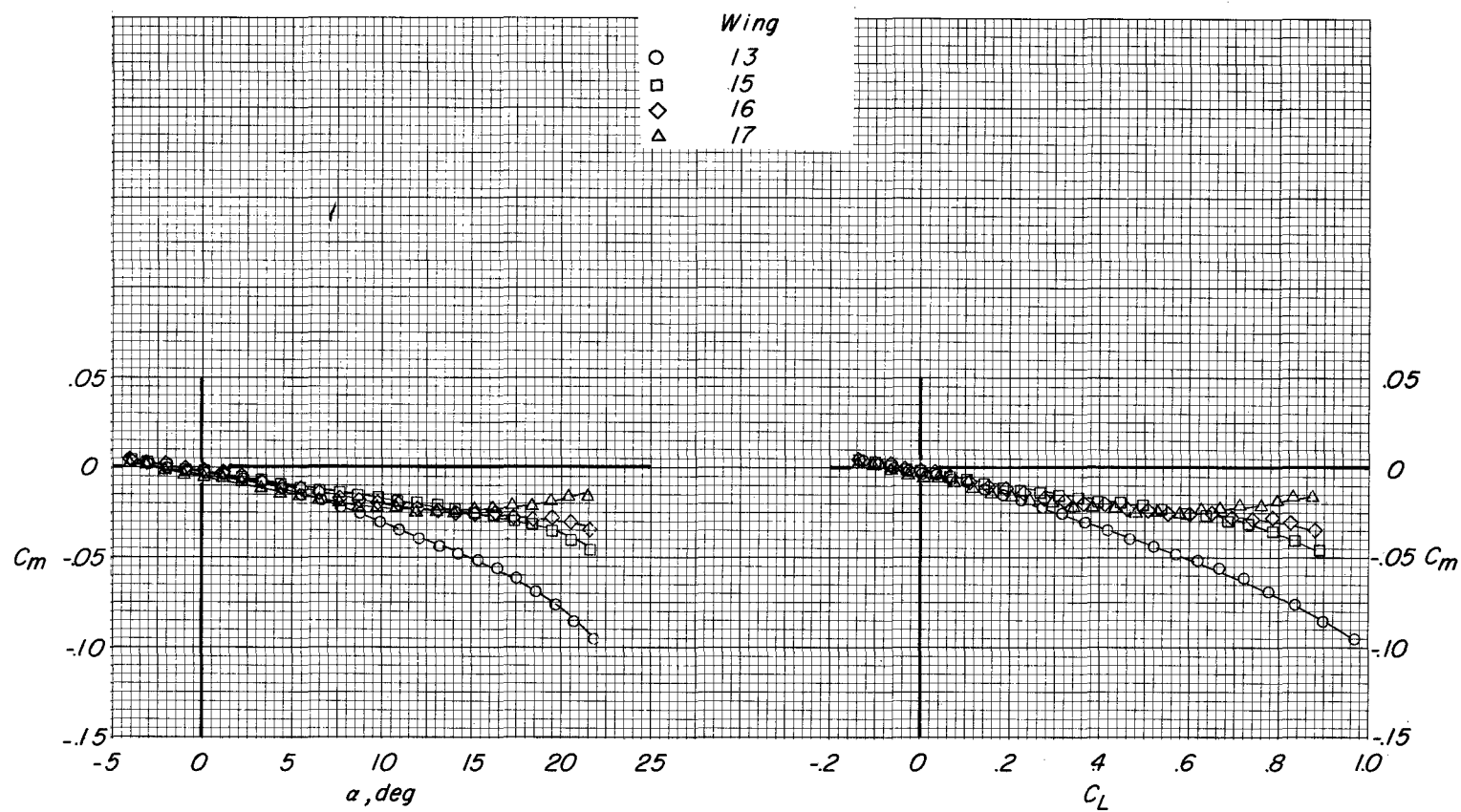


Figure 10.- Concluded.

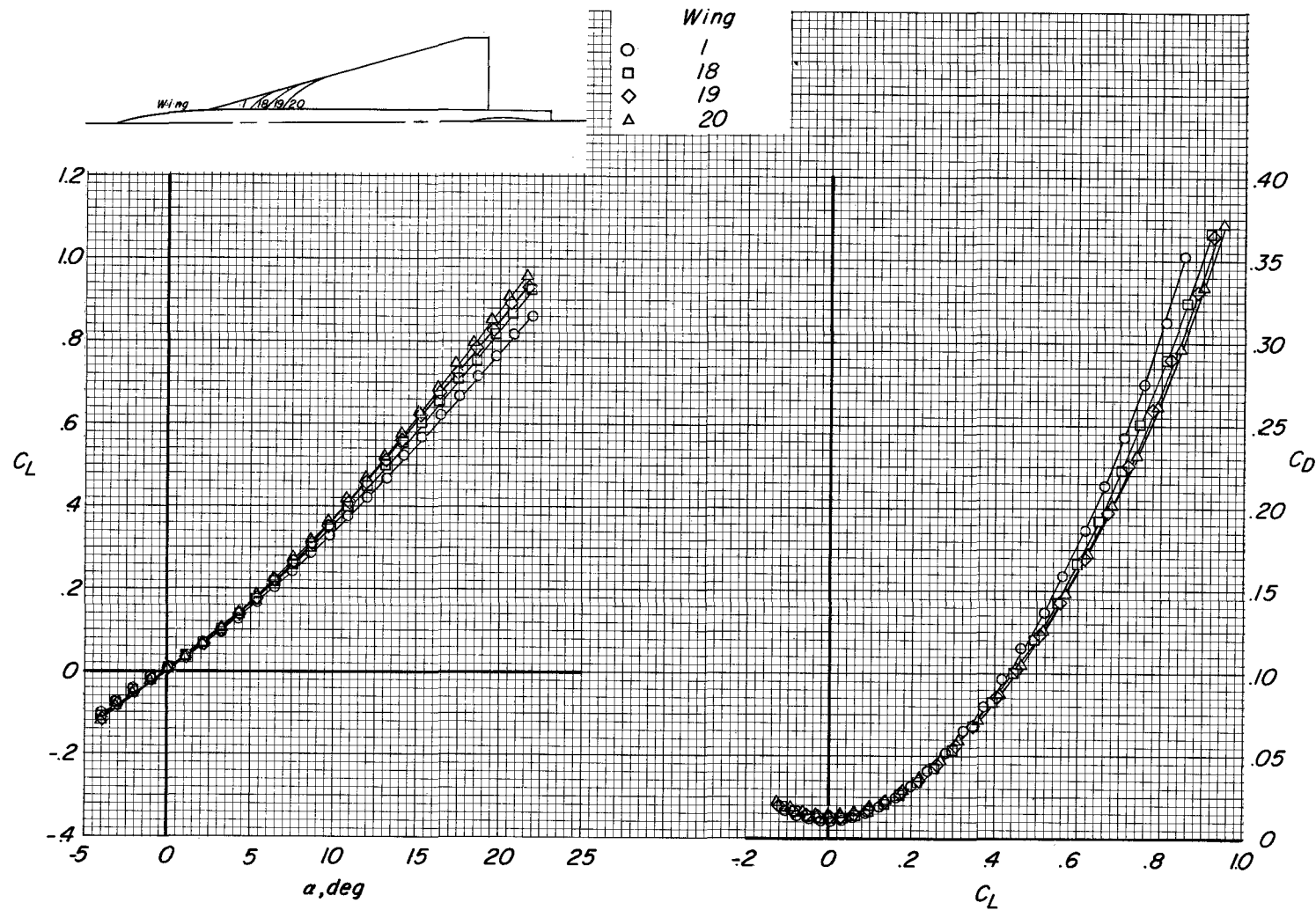


Figure 11.- Effect of wing planform on the longitudinal aerodynamic characteristics. Wings 1 and 18 to 20;  $M = 0.40$ ; leading-edge chord extension off.

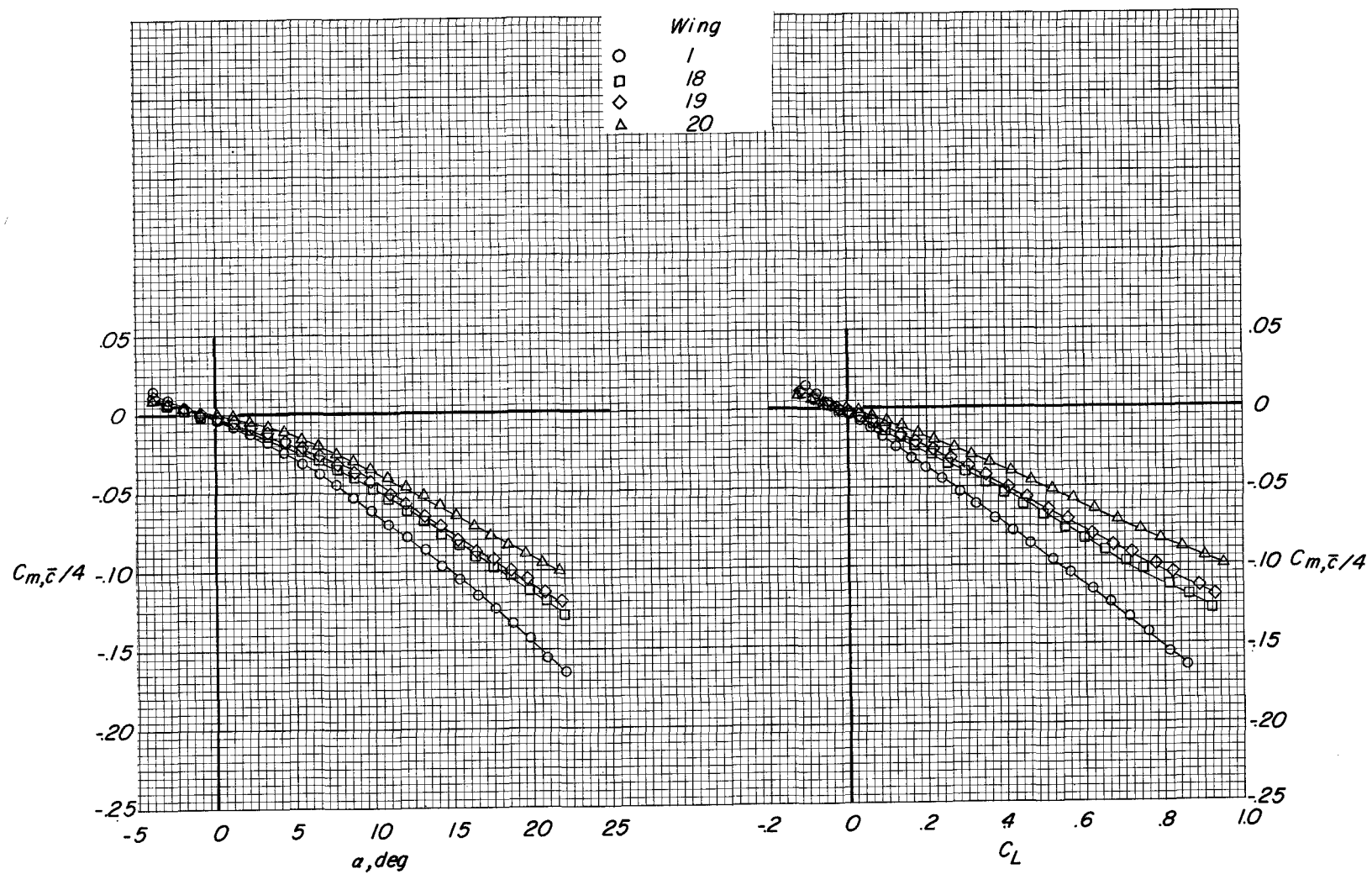


Figure 11.- Continued.

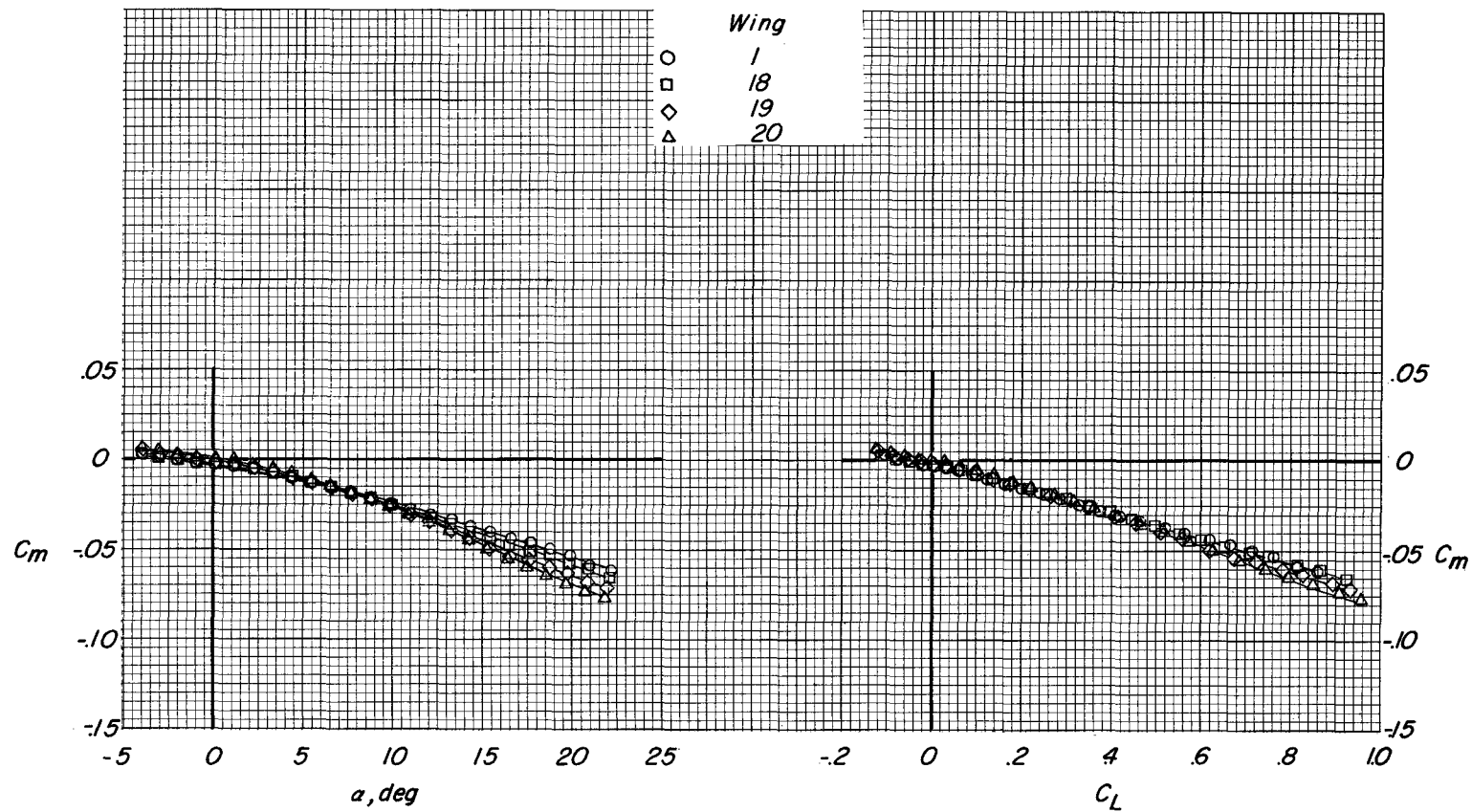


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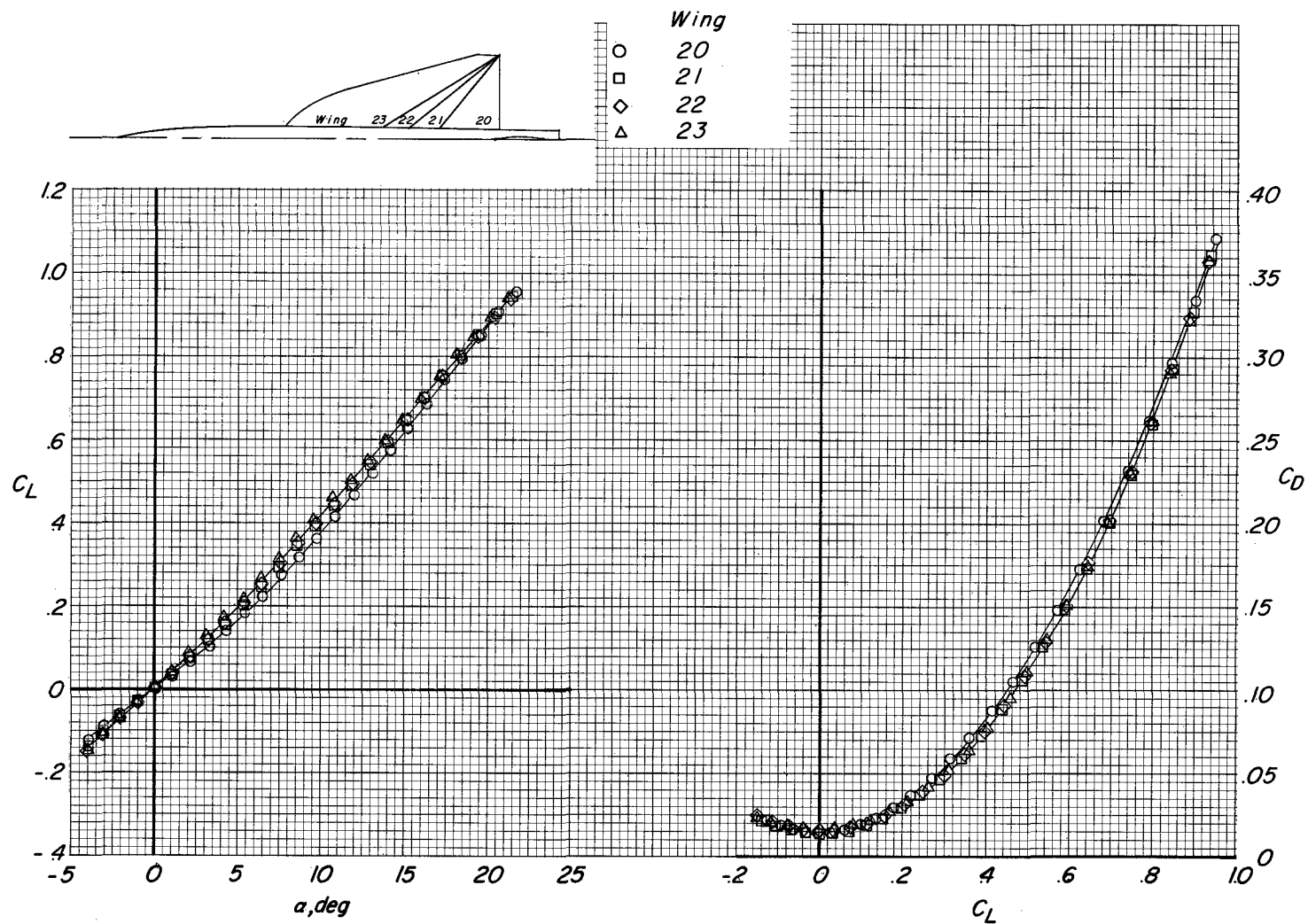


Figure 12.- Effect of wing planform on the longitudinal aerodynamic characteristics. Wings 20 to 23;  $M = 0.40$ ; leading-edge chord extension off.

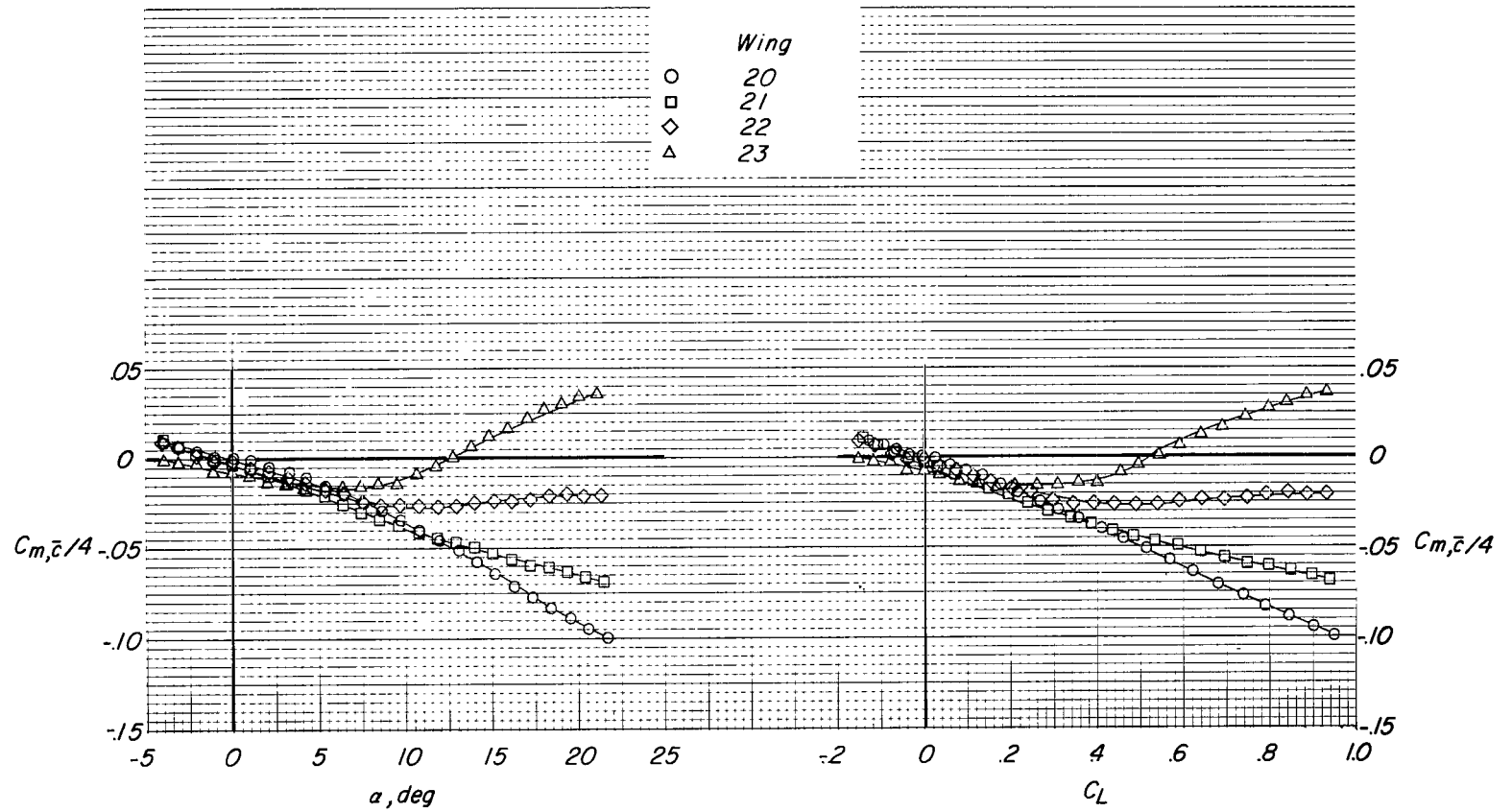


Figure 12.- Continued.

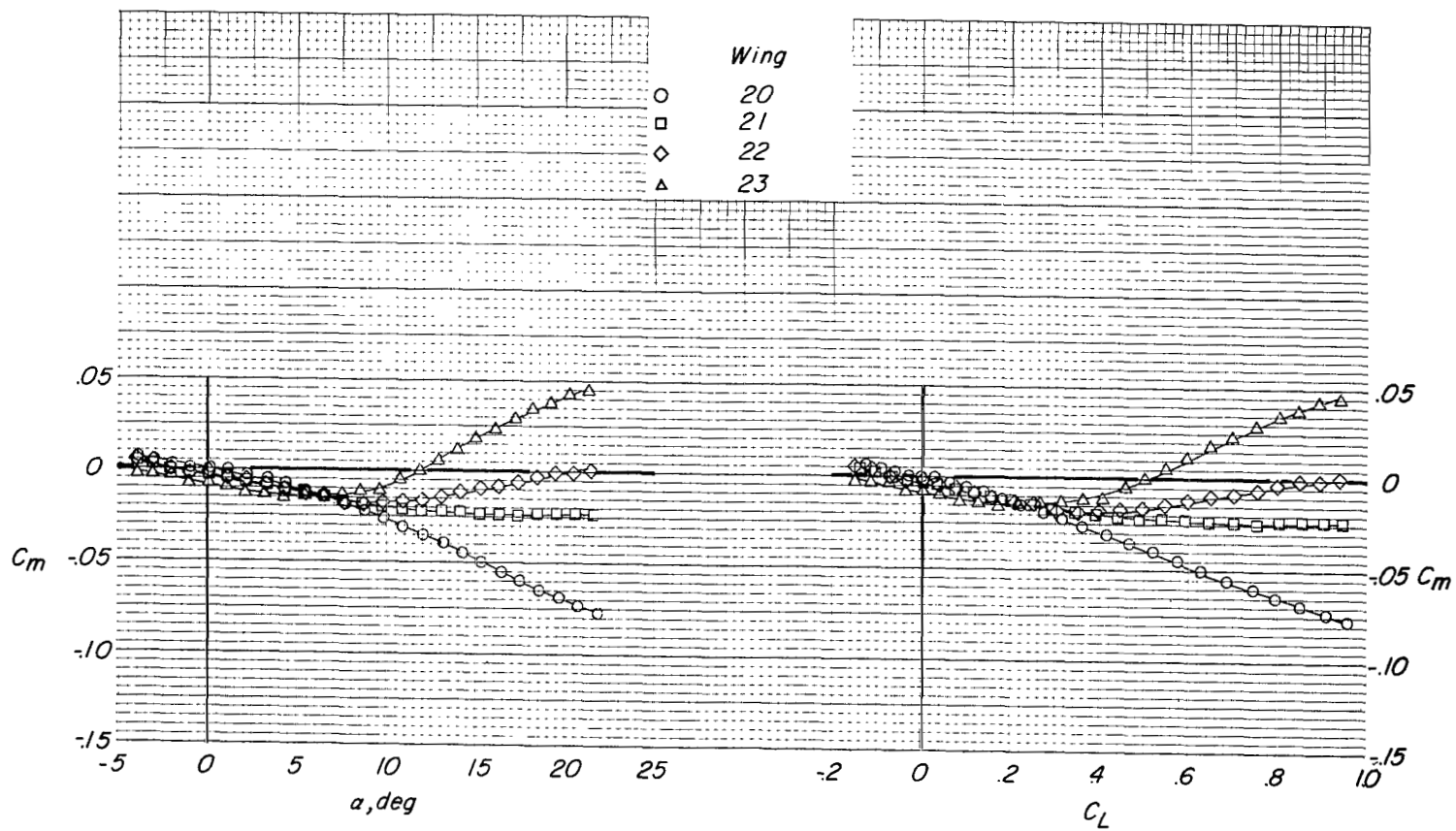


Figure 12.- Concluded.

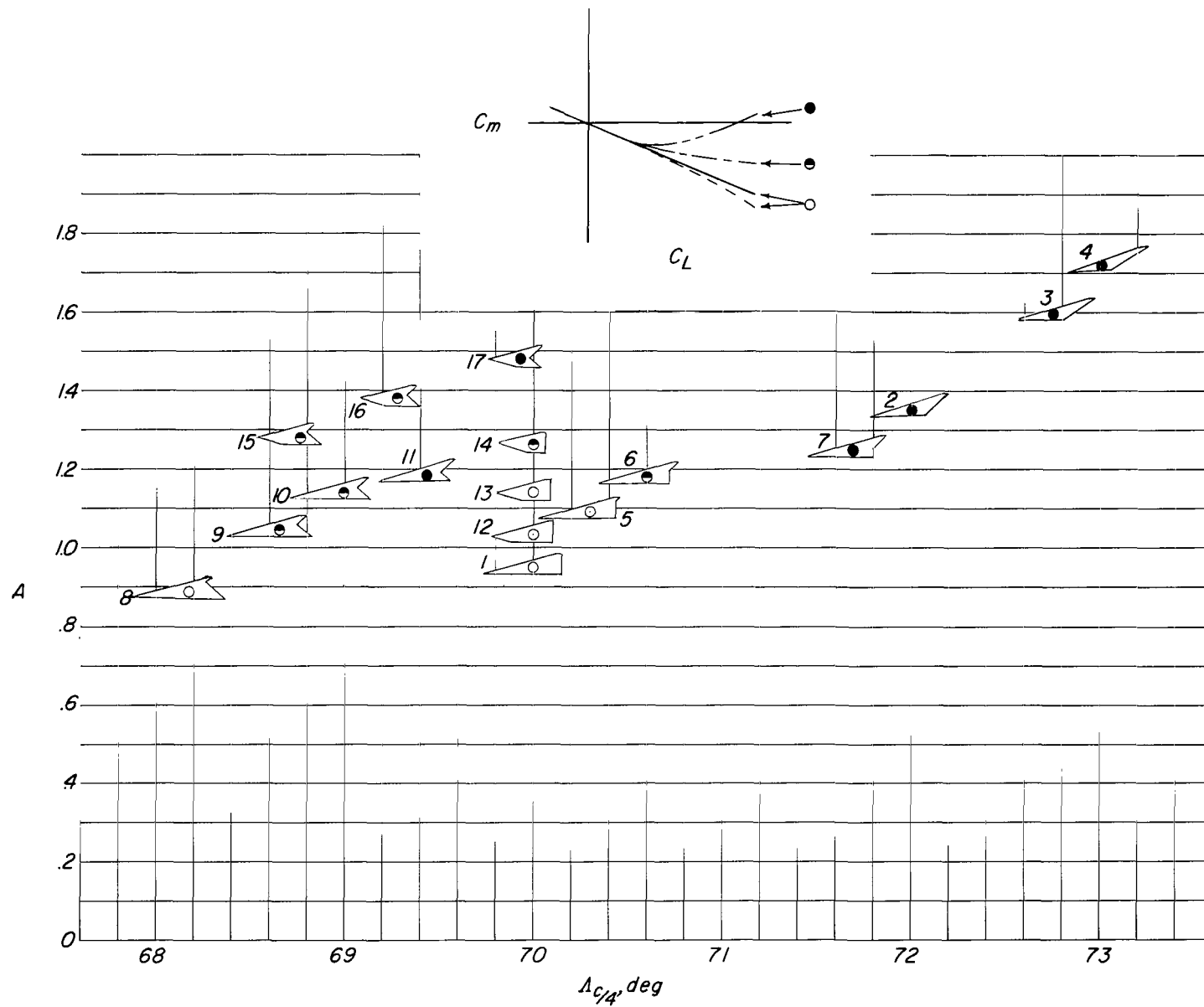


Figure 13.- Geometric variables and the type of pitching-moment curve obtained for the various wings investigated.

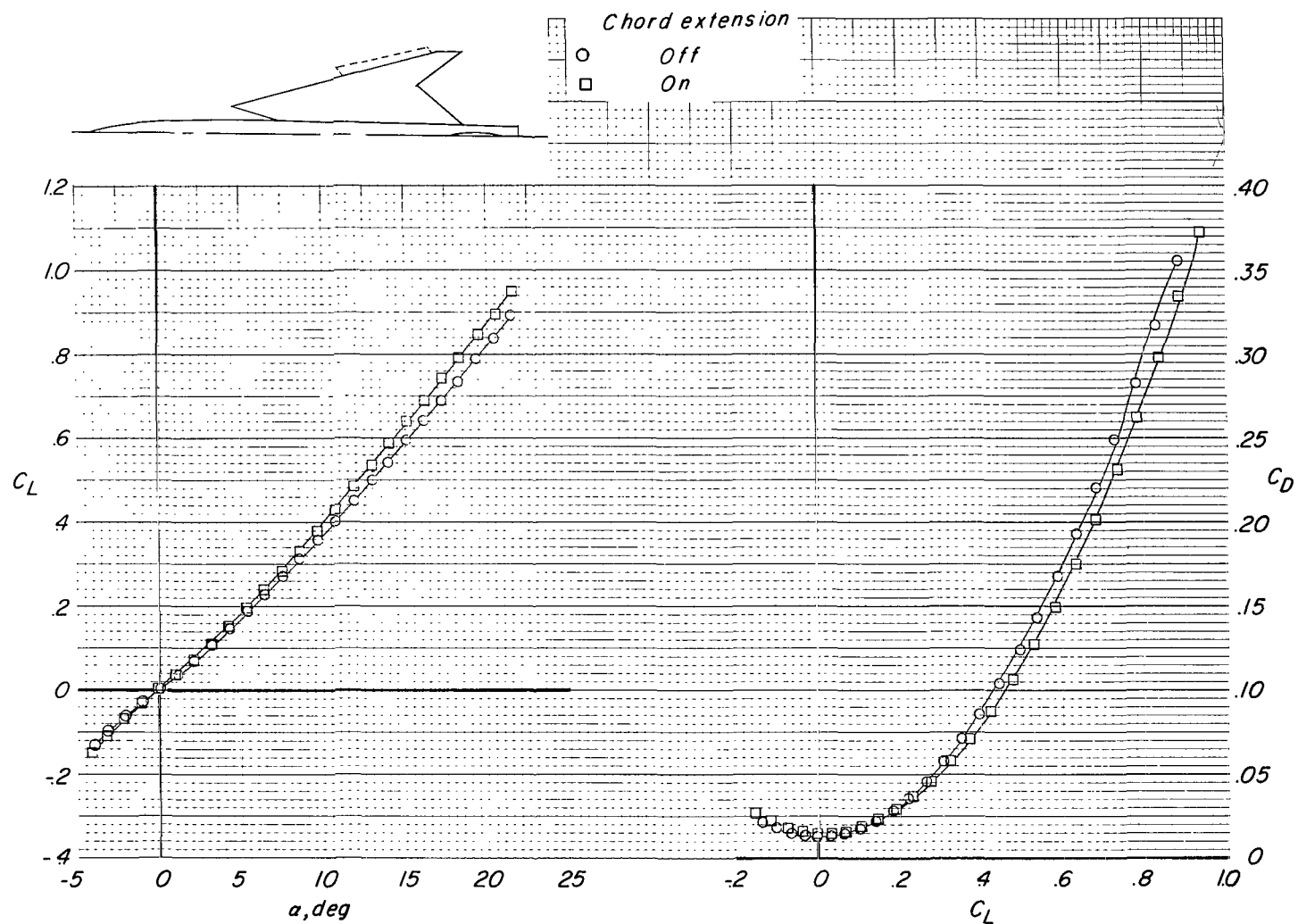


Figure 14.- Effect of leading-edge chord extension on the longitudinal aerodynamic characteristics of wing 15.

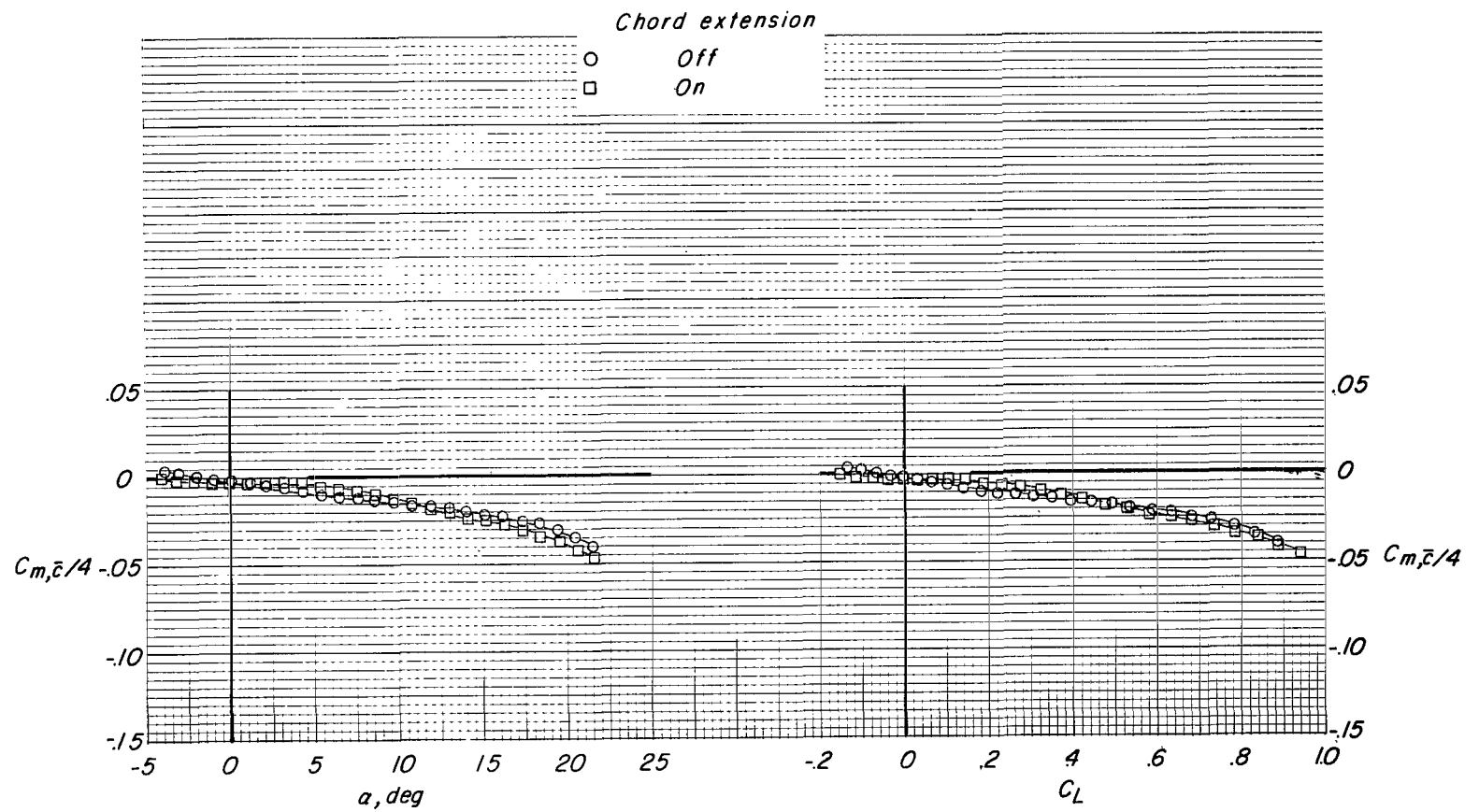


Figure 14.- Concluded.

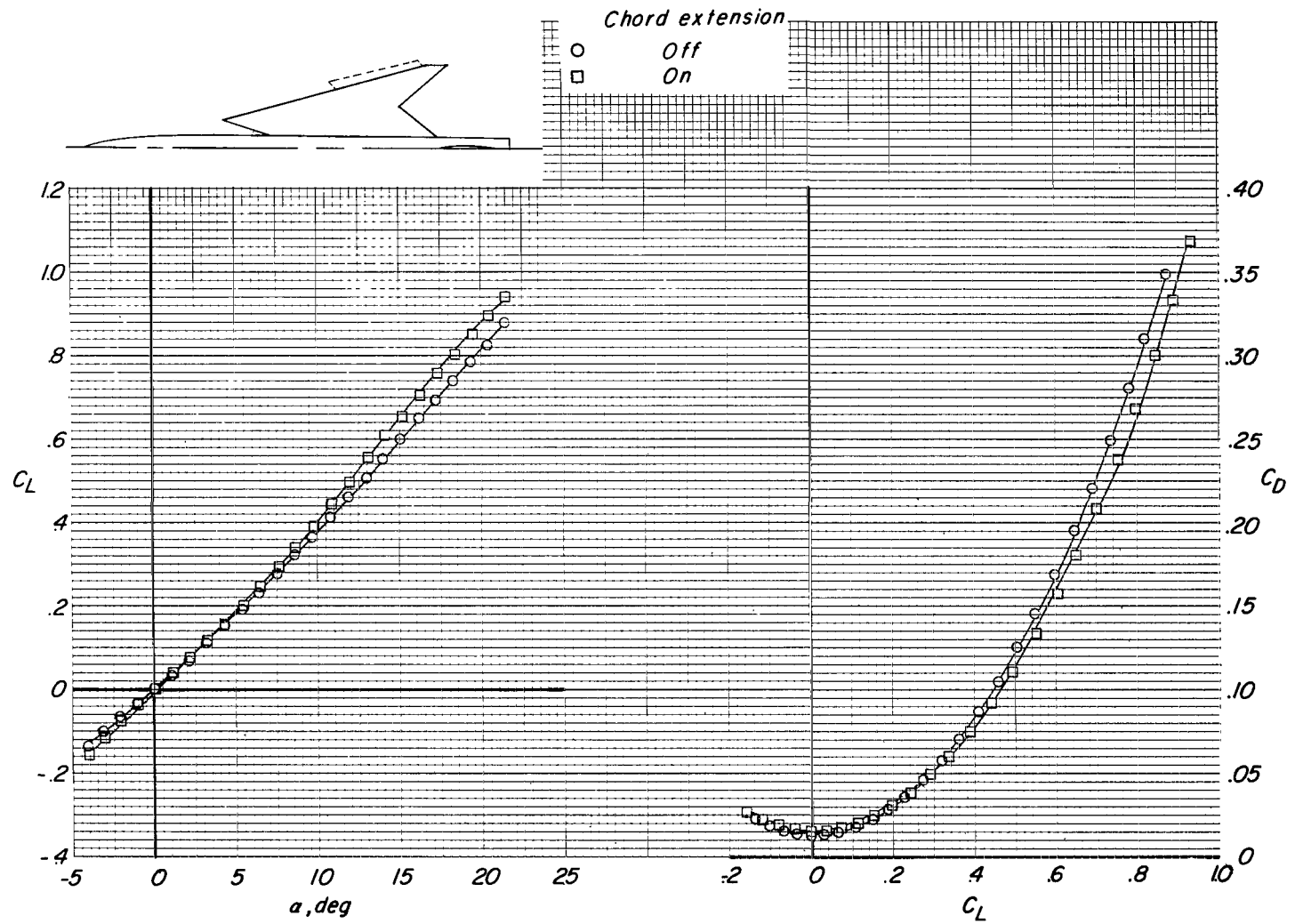


Figure 15.- Effect of leading-edge chord extension on the longitudinal aerodynamic characteristics of wing 16.

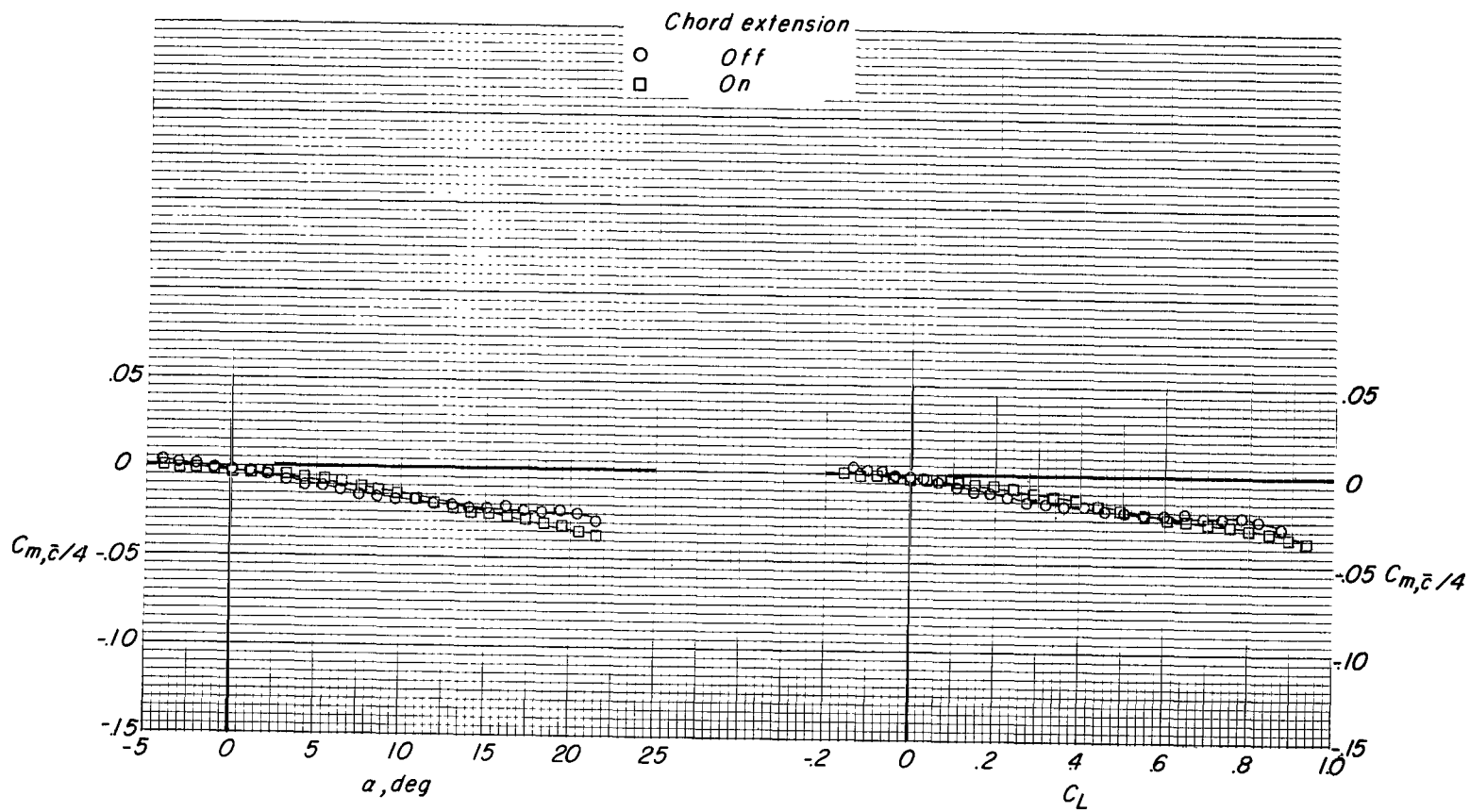


Figure 15.- Concluded.

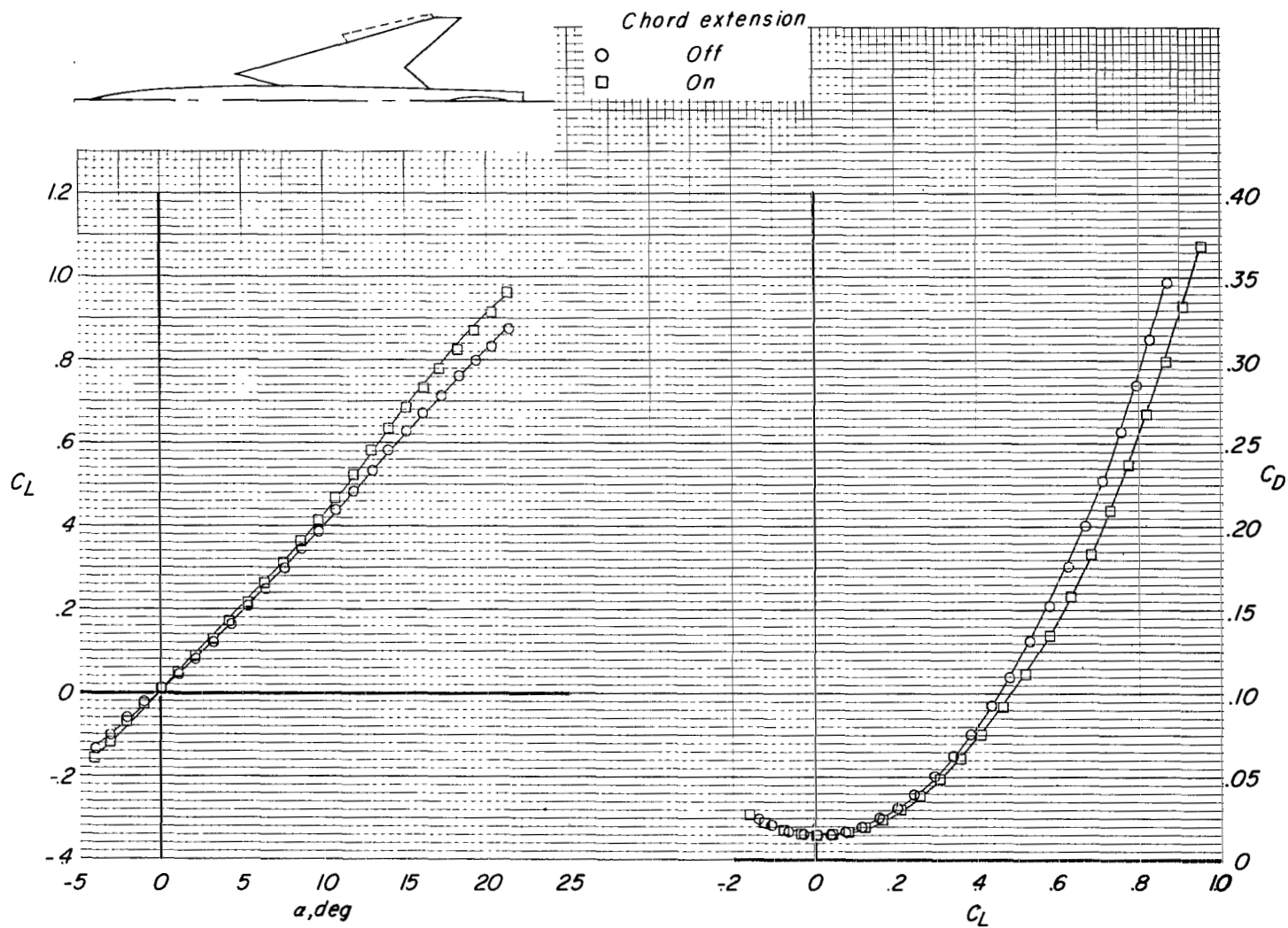


Figure 16.- Effect of leading-edge chord extension on the longitudinal aerodynamic characteristics of wing 17.

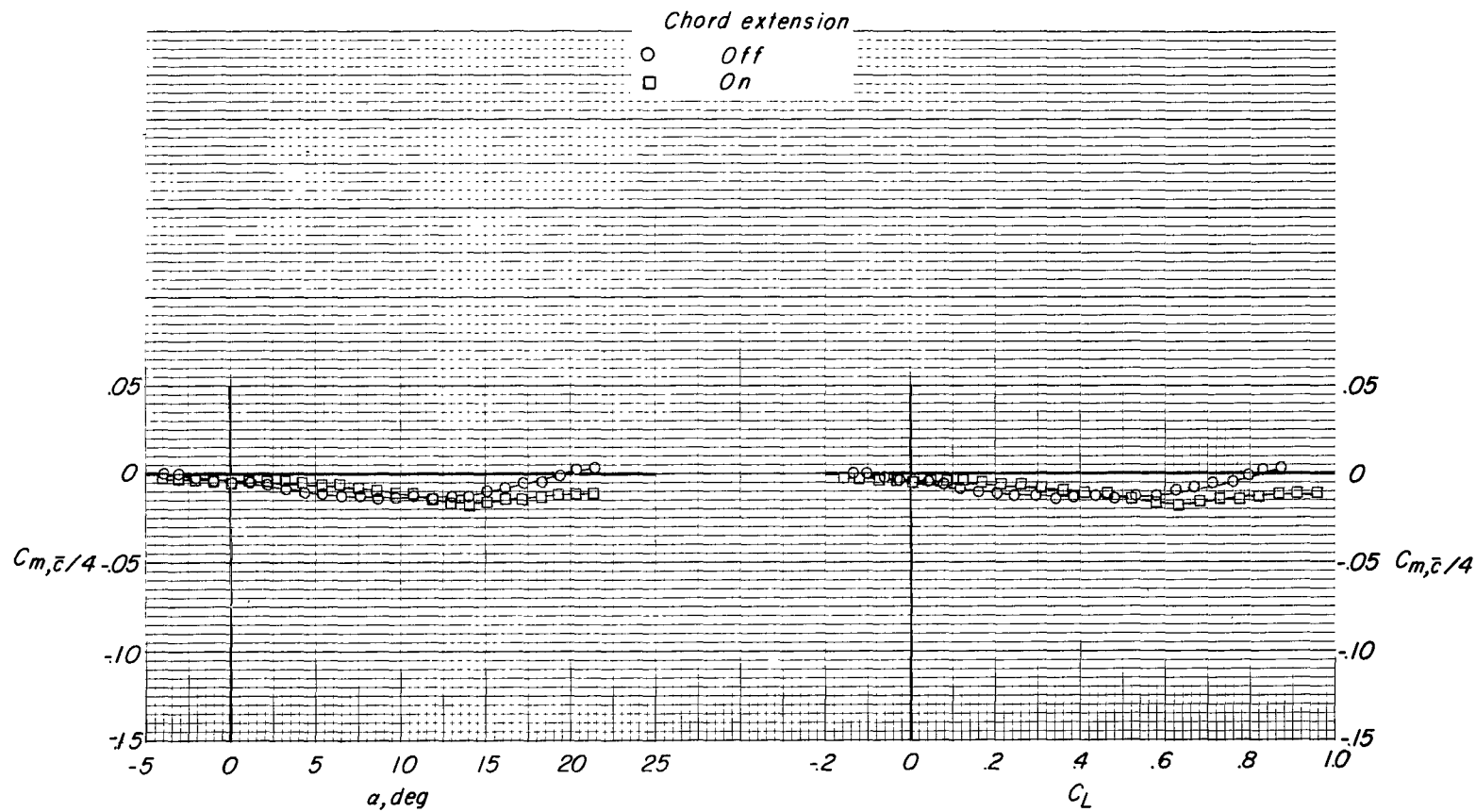


Figure 16.- Concluded.

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